THE DECOMMISSIONING OF BUCHANS UNIT

AND

IMPLEMENTATION OF BIOLOGICAL POLISHING

1994 FINAL REPORT

Prepared for

G. Neary, Buchans Unit, ASARCO
Joint Venture Group at Buchans NFLD
ASARCO INC. - Abitibi-Price Inc.

January 15, 1994

TABLE OF CONTENTS

LIST OF TABLES: APPENDIX T

LIST OF FIGURES: APPENDIX F

LIST OF SCHEMATICS: APPENDIX S

1.0 INTRODUCTION

Since 1988, Boojum Research Limited has been developing the Ecological Engineering decommissioning approach for the Buchans waste management area. Biological Polishing is the main process used. Zinc is removed from the water through co-precipitation with iron hydroxide onto algae. The algal biomass is relegated to the sediment, where the zinc accumulates. Zinc removal is controlled by the residence time, the concentrations of oxidized iron and amount of algal biomass in the ponds. After careful consideration of the geochemical and hydrological conditions, along with the results from a small-scale pond system, the construction of full-scale pond systems for the treatment of effluents has been completed in 1993/1994. The pond systems treat the oufflow from the Oriental East Gloryhole (OEP), which in 1993 was connected to, and now receives overland flow from, the Oriental West Gloryhole (OWP). In 1994, pumping of Drainage Tunnel water to OWP commenced. Therefore, the polishing ponds receive water from three sources combined. Any water characteristic changes upon connecting the gloryholes and the Drainage Tunnel were assessed through geochemical simulations performed prior to the connection of the two gloryholes and the Drainage Tunnel. No potential adverse effects on the biological polishing system were identified from these simulations.

In late 1992, the first series of full scale ponds were built (Polishing Ponds 10 to 13). The performance was tested during the summer of 1993 with varying retention times. Biomass growth was assisted with fertilizer containing phosphate. During 1994, construction of a second series of four ponds (Polishing Ponds 14 to 17) was completed. Effluent was passed through these ponds in late 1994, but biological polishing capacity had not been established before freeze-up.

In 1994, the OWP water quality was assessed. Previous to 1994, the years when the OWP was not connected to the OEP by a culvert, the OWP was acidic (pH 3.5), suspended solid concentrations were low and the water was clear (not turbid), and the

OWP did not thermally stratify during the ice-free season. However, during **1994,** following connection, the OWP pH increased to greater than 5, the water became turbid with iron hydroxide and a thermocline was present over the ice-free season. The OWP now resembles the OEP with respect to pH, turbidity and thermal stratification.

With the iron hydroxide precipitation, significant quantities of zinc are co-precipitated and remain in the OEP. This zinc removal mechanism is being quantified using sedimentation traps. Collection of sedimentation data continued in **1994.** Upon connection, water was observed moving from the OWP to the OEP thus confirming groundwater movement in this direction. Therefore, the OWP is proposed to become an additional vessel for zinc removal. In **1994,** tests were carried out to assess the possibility to optimize zinc removal by biological polishing through installation of growth substrate. Quantification of the effectiveness of growth substrate for algae, comparing fish netting to alder brush cuttings, was performed in Polishing Ponds 10 to 13 and in both gloryholes.

This report summarizes the water quality parameters for the monitoring stations of the Buchans waste management area in Section *2.* In Section 3, the **1994** polishing pond data are summarized and their performance is assessed. Conclusions are drawn in Section **4,** and the recommendations regarding the proposed **1995** program are made in Section *5.*

2.0 LONG TERM TRENDS IN WATER QUALITY

2.1 Oriental East Gloryhole

Zinc concentrations in water leaving the Oriental East Gloryhole (OEP) are shown in Figure 1.

Variation in zinc concentrations'during **994** followed the same pattern as observed in previous years. Zinc concentrations in early in **1994** were similar to **1993** fall concentrations, but greatly declined d ring spring run-off. Zinc concentrations had increased by early summer, but remained at lower levels over the remainder of the year.

In Figure **2,** the flow, in $L.s^{-1}$, leaving OEP is shown. The flow is relatively constant year-round, with the exception of the period during spring run-off when flow rates for the year peak. **As** expected, the flow increased following the addition of Drainage Tunnel water to the OWP, commencing September **27, 1994.**

In Figure **3,** the annual average zinc concentrations for **1989** to **1994** are plotted. It was predicted in the **1993** report that the decline in annual average zinc concentrations would decelerate in **1994** and coming years, given the trends observed up to spring **1993,** where the rate of decrease was **1.58** $mg.L^{-1}.yr^{-1}$. However, upon combining OWP, OEP and Drainage Tunnel waters in **1994,** the decline in the average annual zinc concentrations between **1993** and **1994 (3.16** $mg.L^{-1}.yr^{-1}$) is similar to that between **1991** and **1992 (3.7** $mg.L^{-1}.yr^{-1}$).

2.2 Oriental West Gloryhole

The Oriental West Pit surface water zinc concentrations between March 2, 1989 and December 3, 1994 are shown in Figure 4. Following connection of this gloryhole with the OEP in 1993, the steep decrease in zinc concentrations, regularly observed in late winter/early spring due to fresh water input to the gloryhole, was not noted in 1994. However, a large decrease in annual average zinc concentrations is noted (Figure 5) for the last year. The decrease in the annual average zinc concentration between 1993 and 1994 of 6.5 $mg.L^{-1}.yr^{-1}$ was nearly as high as that between 1990 and 1991, 7.7 $mg.L^{-1}.yr^{-1}$. It is suspected that the large decrease in the annual average zinc concentration between 1993 and 1994 is due to co-precipitation of zinc following iron oxidation, a process now active in a much larger fraction of the OWP volume.

The average zinc concentrations in surface, middle and bottom water of the OWP in March or April of 1988, 1989, 1991, 1993 and 1994 are shown in Figure 6. Prior to connection of OWP with OEP via a culvert, horizontally travelling groundwater entered the OWP from one side and exited through another. This horizontal movement likely accounts for the variation in zinc concentrations with depth prior to 1994. Following the connection of OWP with OEP, groundwater entering OWP now moves vertically to join overflow exiting via the culvert, and variation in zinc concentrations with depth is now much smaller.

2.3 Drainage Tunnel

The zinc concentrations in water emerging from the Drainage Tunnel between January 13, 1990 and December 25, 1994 are shown in Figure 7. Although the Lucky Strike water level has been further increased in 1994, no changes in flow from the Drainage Tunnel are evident (Figure 8).

The annual average zinc concentrations and the annual decreases in the zinc concentrations between 1990 and 1994 for the Drainage Tunnel effluent are summarized in Figure 9. Between 1993 and 1994, the annual average zinc concentration decreased 0.79 $mg.L^{-1}$. A decrease in zinc concentrations with time was not expected, as part of the exposed walls of the Drainage Tunnel were predicted to continue to generate acid and supply zinc. A similar decrease of 0.84 $mg.L^{-1}.yr^{-1}$ as occurred between 1991 and 1992. These decreases in annual average zinc may indicate a depletion of zinc in the sludge in the tunnel and the exposed walls.

2.4 Waste Rock Pile Seepages

In Table 1, all water quality data (1989 to 1994) for ARUM Ponds 7, 8 and 9 are presented. The parameters measured, such as pH, conductivity and acidity do not suggest many changes between Pond 7 and 8, but, generally, a reduction in acidity is noted by the time water reaches Pond 9. This does suggest some metal removal is taking place, but it is not clear if it is due to dilution or the ARUM process. In Figure 10, zinc concentrations in Pond 7 are compared to Pond 9 for 1989 to 1994, which shows a reduction in zinc from, on average, 63 $mg.L^{-1}$ to 27 $mg.L^{-1}$.

On July 13, 1994, the waste rock pile seepage area was assessed to determine a potential ARUM configuration for the seepages. Water samples were collected and flows determined in the vicinity of the Waste Rock Pile (WRP). Stakes with flagging tape were placed at all sampling locations. Temporary simple flumes were installed at each location (Schematic 1).

At the time of sampling, seepage water was flowing from the base of the WRP north of polishing Pond 10 through a ditch. The flow, measured at station WRP-A, was 2.1 $L.min^{-1}$ (Table **2).** Flow in the ditch arrives at station WRP-B (12 $L.min^{-1}$), location just upstream from where Polishing Pond 12 leakage enters the ditch. This ditch was collecting an additional 10 $L.min^{-1}$ between WRP-A and WRP-B. This zone was also collecting some acid as well, since the acidity decreased by only 56 %.

The combined flow of the seepage and leakage water was measured at station WRP-F, located just before flow enters Polishing Pond 9. Here the flow was 15 $L.min^{-1}$, indicating that the Polishing Pond 12 leak amounts to 3 $L.min^{-1}$. This polishing pond leak is contributing 136 $mg.L^{-1}$ alkalinity to the ditch, neutralizing some of the WRP seepage's acidity, as indicated by a higher pH (4.37), lower acidity (132 $mg.L^{-1}$) and formation of precipitate after mixing of the seepage with leakage in the ditch at station WRP-F (Table 2).

There is a second seepage path forming just north of station WRP-C. The flow of this seepage was only 0.6 $L.min^{-1}$, and the water contained only moderate acidity (188 $mg.L^{-1}$). This seepage contained 38.6 $mg.L^{-1}$ zinc at the time of sampling. Below station WRP-C, the surface flow percolates into the peat area between station WRP-C and Polishing Pond 7. In this area, there was no surface water flow which could be measured at the time.

The entire peat area surrounding Polishing Ponds 7, 8 and 9 was saturated. After installing a flume in the path between Polishing Pond 7 and 8, a very small flow could be measured (0.2 $L.min^{-1}$). This water contained 298 $mg.L^{-1}$ acidity and 55 $mg.L^{-1}$ zinc. Similarly, a flume installed in the stream path between Polishing Pond 8 and 9 allowed measurement of a flow of 0.6 $L.min^{-1}$. Water collected at this station contained less acidity (243 $mg.L^{-1}$) and zinc (35.1 $mg.L^{-1}$) than in water leaving Polishing Pond 7.

As noted above, flow from the WRP seepage ditch and leakage from Polishing Pond 12 enters Polishing Pond 9. This pond was cloudy with white precipitate, which also covered the pond bottom. The pH of Polishing Pond 9 was 4.37, the acidity was 132 $mg.L^{-1}$ and contained 33.4 $mg.L^{-1}$ zinc, values all very similar to station WRP-F.

Two additional samples were collected in the Waste Rock Pile area. Water was sampled at station WRP-D, located in the pool of water 0.5 m deep at the base of the waste rock pile. Although no visible inflow or outflow was observed, this water is not rain water, as it contained 592 $mg.L^{-1}$ acidity and 105 $mg.L^{-1}$ zinc, the highest concentrations of any of the WRP stations sampled during the site visit.

The second sampling location, WRP-E, is located in a path of subsurface seepage moving southward from the western edge of the waste rock pile. This flow is apparent from the saturated soil conditions and a dense cover of exclusively moss along the pathway. A 20 cm hole was excavated in the moss layer and was lined with sheets of moss. A water sample was collected from this hole two hours later. This pore water contains 502 $mg.L^{-1}$ acidity and 81 $mg.L^{-1}$ zinc. A flow rate could not be accurately measured in these conditions and was not attempted.

2.5 Lucky Strike Gloryhole

The surface water zinc concentrations in the Lucky Strike Gloryhole in samples collected between April 10, 1990 and December 3, 1994 are presented in Figure 11. Although the surface water concentrations of zinc show an increase toward the end of the year, similar to the previous years since flooding commenced, the annual average concentrations have increased compared to the year before (Figure 12).

Zinc concentrations in water samples collected from various depths in April of 1989, 1991, 1992, 1993 and 1994 indicate that a concentration gradient of zinc with depth prevails (Figure 13). The average zinc concentrations in samples taken from depths of 13.1 - 17.7 m were typically much higher that samples collected 1.5 m below surface. This trend was most pronounced in 1994 (Figure 13). The concentration gradient, increasing with depth, suggests that a chemocline might form in the pit. This possibility should be examined using all available data and the implications of such a development should be assessed.

Changes in the surface water elevation of the Lucky Strike Gloryhole pond are shown in Figure 14. Tailings Pond 1 water was siphoned into the gloryhole during the ice-free season in 1992, 1993 and 1994. The water level increases are plotted together with the Drainage Tunnel annual average flows, in $L.s^{-1}$. As was the case in the previous years, the water level in the Lucky Strike Gloryhole does not appear to be affecting the flow from the Drainage Tunnel.

2.6 Tailings Pond 1

Zinc concentrations in ouflow from Tailings Pond 1 between May 12, 1990 and December 25, 1994 are presented in Figure 15. Ouflow, in $L.s^{-1}$, from Tailings Pond 1 measured between May 12, 1990 and December 25, 1994 is shown in Figure 16. This tailings pond is not expected to show any major changes in zinc concentrations, as zinc is at the equilibrium concentration in the system. The flows in 1994 display the same pattern as in the previous years, reflecting seasonal variation in run-off.

2.7 Tailings Pond 2

Zinc concentrations in ouflow from Tailings Pond 2 between May 12, 1990 and December 25, 1994 are presented in Figure 17. Generally, in 1994 zinc concentrations were lower than in previous years.

Ouflow, in $L.s^{-1}$, from Tailings Pond 2 measured between May 12,1990 and December 25, 1994 are shown in Figure 18. The flow pattern of the TP-2 drainage basin has not changed since 1990, displaying the annual input during spring run-off and decreases in flow volume over the remainder of the year.

Annual average surface water zinc concentrations for Tailings Pond 2 are presented in Figure 19. The predicted decrease in the annual average zinc concentration due to dilution with fresh water run-off from the basin is still evident between 1993 and 1994

($0.4\ mg.L^{-1}.yr^{-1}$ decrease). From zinc concentration maxima and minima presented in Figure 19, it can be seen that, in 1994, relatively large fluctuations in zinc concentrations occurred.

Daily zinc loadings in $kg.d^{-1}$ (measured zinc concentration x measured flow for a given date) between May 12, 1990 and December 25, 1994 are presented for Tailings Pond 2 in Figure 20. The zinc loading directly reflects the flow pattern.

2.8 Simms Brook and Buchans River at Highway Bridge

Zinc concentrations in Simms Brook between May 12,1990 and December 3,1994 are shown in Figure 21.

Simms Brook flow, in $L.s^{-1}$, between May 12, 1990 and December 3, 1994 are given in Figure 22. Zinc concentrations in samples collected between January 13, 1990 and December 3, 1994 from the Buchans River and the Highway Bridge are shown in Figure 23. **As** the concentrations at these monitoring stations are relatively low, changes due to the decreases in loading from the treatment in the Polishing Ponds and the decrease in TP-2 cannot be discerned.

3.0 BIOLOGICAL POLISHING OF DRAINAGE TUNNEL-OWP-OEP EFFLUENT

3.1 Current Limnology and Chemistry of OWP and OEP

Since flooding of the OWP in 1987, the water has been acid (pH 3.5; see September 1993 example profile, Figure 23) and the water column has been very clear (i.e. no turbidity). Good light penetration occurred during the ice-free season. With good light penetration, the entire water column was heated during spring and summer months, and no thermal discontinuity formed in the pit. The pit water likely contained enough dissolved oxygen to oxidize any ferrous iron entering the pit in ground water, and dissolved iron levels were kept low due to precipitation of ferric hydroxide.

The OWP's chemistry and limnology has changed following joining of OWP with OEP and the subsequent lowering of OWP's water level by 40 cm. The pH has increased from the typical pH 3.5 to pH 5.8 - 6.7, the water column is turbid with ferric hydroxide particles and dissolved oxygen concentrations are close to zero below a 3 m depth (Figure 24).

On July 11, 1994, there was a sharp temperature gradient between the surface (17.4°C) and at a depth of 3 m (8.8°C:Figure 24). Below 3 m, the temperature gradually declines to 5.8 "C at the bottom (12 m). The upper warm, floating layer of water is termed the epilimnion. The stratum where the temperature rapidly decreases with depth is termed the metalimnion. Below 3 m, the cold water stratum is termed the hypolimnion.

The surface water contained close to saturated dissolved oxygen (D.O.) concentrations. The D.O. concentration sharply decreased at a depth of 3 m. Below 4 m, there was less than 1 $mg.L^{-1}$ D.O. The temperature and dissolved oxygen profiles indicate that only the top 3 m of the OWP were circulating and vertically mixing at the time of sampling.

The surface zinc concentration was 17.3 $mg.L^{-1}$ on July 11 (Table 3), while the zinc concentration was 21.3 $mg.L^{-1}$ at a depth of 6 m below the surface in the hypolimnion, and 23.3 $mg.L^{-1}$ at the bottom of OWP. This indicates that zinc is precipitating in the epilimnion, likely due to co-precipitation with ferric hydroxide in the epilimnion.

The acidity was relatively low in the surface water (35 $mg.L^{-1}$) compared with 6 m and bottom water (168, 226 $mg.L^{-1}$ respectively; Table 3). This acidity is likely due to ferrous iron concentrations, and to a minor degree, higher zinc concentrations, in the hypolimnion. Alkalinity was slightly higher (59 $mg.L^{-1}$) in surface water than 6 m (50 $mg.L^{-1}$) and bottom water (41 $mg.L^{-1}$).

The OEP limnology is summarized in Figure 25. No changes are noted as was expected based on the evaluation of the geochemistry which was carried out prior to the connection with the OWP.

3.2 Long Term Limnocorral Performance in OWP and OEP

The LC1, LC2, LC3 (OWP), LC4, LC5 and LC6 (OEP) limnocorrals have been in place, as of July 11, 1994, for 1,879 days, or over 5 years.

The data on their performance are presented here for completeness, although implementation of the ARUM process is not anticipated for the gloryholes, due to the groundwater inputs which do not facilitate an appropriate flow regime for ARUM. This process is proposed to be used in the area of the seepages from the waste rock pile.

Since approximately one year after set-up, the surface and bottom pH in the LC2, the OWP limnocorral to which peat was added, has remained relatively high (Figures 26a and 26b), and surface and bottom water zinc concentrations have remained low (< 5 $mg.L^{-1}$; Figures 27a and 27b), compared to the control limnocorral (LC3). The sawdust-amended limnocorral (LC2) has not performed as well as the peat amended limnocorral.

As the **OEP** at large has pH values consistently close to neutrality, pH can not be used as a performance criterion for the OEP limnocorrals (Figure 28a and 28b). However, is was interesting to note that addition of peat caused a release of acidity which lower LC5's pH in the 150 days.

As observed for the peat-amended limnocorral in the **OWP** (LC2), surface and bottom water zinc concentrations the peat-amended LC5 in the **OEP** were consistently low since one year after set-up until day 1,300 (Figures 29a and 29b). Analysis of the most recent samples, collected on. July 11, 1994, indicates than bottom water zinc concentrations have increased in LC5. It appears that the organic carbon required by the bacteria may be finally depleted after 5 years without replacement.

3.3 Iron Hydroxide Sedimentation Rates

The 4 m, 11 m and 20 m deep Sedimentation Traps were retrieved on July 11 and the contents sampled. The estimated sedimentation rates in the **OEP,** in kg per day, between August 1993 and July 11, 1994 are shown in Figure 30, for comparison to all other sedimentation rates estimated to date.

In the August 1993 to July 1994 period, approximately 90 to 100 kg of precipitates were settling, according to the 4 m and 11 m sedimentation traps. These results are comparable to the previous period's sedimentation rates for these depth (100 to 200 kg per day in the pit).

The sedimentation trap positioned near the bottom of the pit collected a very large amount of sediment during the ice free season, equivalent to 8,000 kg in the **OEP** per day. In the most recent period, this trap again collected a large amount of sediment, equivalent to 2,000 kg per day for the pit. It is possible that after years of sediment accumulation on the pit walls, significant sloughing of previously settled precipitate takes place in the lower part *o* the gloryhole which is being collected by the bottom sedimentation trap.

Unfortunately, the sedimentation trap from the last sampling period in **1994** at the bottom the OEP could not be retrieved. In the period (July - September, **1994),** this trap collected less sediment than in the summer period of the previous years, suggesting that less sedimentation is taking place recently. Sedimentation has also been quantified for the OWP in **1994.**

Although the overall chemistry of OWP now resembles that of OEP, precipitate formation and sedimentation appears to be lower than in the OEP (Figure **30).**

3.4 Biological Polishing in OWP and the Polishing Ponds

In the years before **1994,** the pH of OWP water was 3.5, and very little suspended or attached algae was visible in the OWP. However, with higher pHs in **1994,** periphytic algae are growing on all substrates in the top **1** m of the water column, where adequate light is available. With the addition of the Drainage Tunnel water to the OWP, there is no reason to believe that these chemical conditions will not prevail in the long term.

Therefore it would be useful if biological polishing capacity can be established in the OWP to retain as much of the iron hydroxide in the gloryhole. Algal growth was tested on netting and on brush suspended during the **1994** summer season. The results are presented together with the results obtained from the Polishing ponds later in this section.

3.4.1 Polishing Ponds 1 Through 6

In July 1994, essentially no flow was entering the old polishing pond, as they were no longer being maintained. The entrance to Pond 1 was cleared, and the weirs were cleared of debris. The flow was set at 8.6 $L.min^{-1}$. At this rate, the retention time of PP1 through 6 (max vol=243 m^3) was only 21 days maximum. However, iron and algal biomass accumulation in the ponds has significantly reduced the volume since original volume estimates were made, and actual retention times are lower.

Water samples were collected on July 12, 1994, two days after flow-through was re-established. Flows, pH, conductivity, redox were measured in the field, and zinc concentrations were determined by ASARCO on whole samples. The results are summarized in Table 4.

The zinc concentration entering the ponds was 11.85 $mg.L^{-1}$, while at PP6 ouflow, the zinc concentration was 2.45 $mg.L^{-1}$. This amounts to a reduction of 79 %.

The acidity and alkalinity titration curves are shown in Figure 31a and 31b. The acidity and alkalinity decreased between PP1 inflow and PP6 outflow, due to removal of carbonates with zinc precipitation, and hydroxides with iron and zinc removal. Similar acidity (< 50 $mg.L^{-1}$) and alkalinity (< 200 $mg.L^{-1}$), and this same trend of decreasing acidity and alkalinity with passage of water through the polishing ponds, were also observed in 1993 (see Figures 29a and 29b in 1993 report). These gradual changes indicated by the titration curves are a good monitoring tool for the functioning of the Biological Polishing ponds.

Alder branches with attached algae and moss were sampled from each pond as in the previous years to quantify the biomass and zinc adsorption.

3.4.2 Polishing Ponds 10 through 13.

Water was sampled from inflow to Polishing Pond 10, and at the ouffiow weirs of polishing Ponds 10, 11, 12 and 13 (Schematic 1). The pH, conductivity and redox were measured in the field, and zinc concentrations were determined by ASARCO on whole samples.

Samples were returned to Boojum's lab where acidity and alkalinity were determined. The acidity and alkalinity titration curves are presented in Figure 32a and 32b. As observed for Polishing Ponds 1 through 6, acidity and alkalinity diminish in water passing through the ponds. Zinc concentrations decreased from 14.1 $mg.L^{-1}$ at PP10 inflow to 6.025 $mg.L^{-1}$ at PP13 ouffiow.

The calculated retention of new water entering an open pond will typically exceed the actual retention time of this water. Direct flow of new water along a path of least resistance from the inlet to the outlet reduces this water's retention time. Meanwhile, the retention time of water in other areas of the pond will be much longer than the calculated retention time.

These phenomena are especially pronounced in winter when ice covers the pond. In the ice-free season, smaller stagnant areas are maintained due to wind-driven circulation of a larger fraction of the pond volume. However, with the addition of alder branches as substrates, wind-driven pond circulation is reduced, and the volume of stagnant water is increased.

In an effort to directly examine the flow pattern in the polishing ponds, the tracer rhodamine was added at the inflow of Polishing Pond 10 and was traced for 8 hours as it passed through Polishing Pond 10 and half way to Polishing Pond 11 ouffiow, whereupon the tracer concentration was too dispersed and dilute to see. The front of the tracer at various times after addition is shown in Schematic 1.

Dense algae was growing over the substrate of Polishing Pond 10, as this pond has been in place for a longer period than Polishing Ponds 11, 12 and 13. In these latter ponds, no distinct pattern ***of*** algal growth in relation to possible flow pattern was observed. These observations indicate that short-circuiting is not significantly reducing the actual residence time of water entering each polishing pond.

3.4.3 Polishing Ponds Performance Assessment

In the 1993 final report, the zinc removal data for Polishing Ponds 1 through 6 with respect to retention time was 'examined. From this analysis, it was projected that adequate removal of zinc upon passage of OEP water through polishing ponds could be achieved with a **45** day retention time (all data regression line, Figure 33), and during periods of high algal growth, with a 20 day retention time (Top 8 data regression line; Figure 33).

In 1992 and 1993, there were periods when Polishing Pond 10's retention time adequate for substantial zinc removal, and these data generally concurred with predictions based on the Polishing Pond **1** through 6 data. However, flow rates through the scaled up Polishing Pond 10 through 13 system were too high in 1993 to achieve adequate retention time for significant zinc removal.

In 1994, flow has been regulated through the scaled-up system so to achieve adequate retention time. By July 13, the system had be operating for 3 weeks since berm repair and refilling. Abundant periphytic algae was present only in Pond 10. Zinc concentrations in each pond were successively lower, and the overall system was removing 57 % of the zinc during an estimated retention time of 38 days (Figure 34).

Zinc removal performance has since been improving, and on July 31, over 70 % of the zinc was being removed with a retention time ***of*** only 22 days.

The August performance was exceeding expectation, reaching over 90 % removal of zinc in PP 13. This increase in performance was due to increased periphyton growth rates in the ice-free season, combined with an increase in retention time in the spring, compared to the previous winter months.

In September, 1994, the zinc removal performance sharply dropped off to 25% to 40%, due to the reduction in retention time, at the time when all OEP discharge was directed through the system during construction of Polishing Ponds 14 - 17. Overall, the data collected to date confirm that a retention time of 30 days appears suitable for > 90% removal of zinc during the growing season (Figure 35).

3.4.4 Algal Periphyton Growth

In 1994, periphyton was quantified on alder branches as performed in previous years ("Jelly" in Table 5). In addition, a small experiment was set up to compare periphyton growth on a bundle of 30 cm long, freshly cut alder branches ("branch bundle", Table 5) with growth on fish netting ("periframe", Table 5).

As described in previous reports, periphyton growth estimates, based on total biomass per unit area per day since alder branch placement, are likely underestimates, as sloughing of biomass is not accounted for. Branches collected in 1994 had been in place for as long as 1776 days, or close to 5 years, and several seasons of jelly had likely fallen off by the time of sampling. For the record, the average growth rate for the 11 samples collected was 0.46 $g.m^{-2}.d^{-1}$. The surface areas of branches used in these calculations were based on the 1989 estimate of the ratio of surface area to branch weight of 0.00272 $m^2.g^{-1}$ (PP1 to PP6, PP10).

Much higher average growth rates were calculated for the periframe and branch bundle samples collected in 1994 after only 34 to 50 days growth. The average growth rate of periphyton on the periframes was 6.3 $g.m^{-2}.d^{-1}$ (surface area, 30 by 30 cm area of netting), while for the branch bundles, it was 2.53 $g.m^{-2}.d^{-1}$ (1994 estimate of the ratio of surface area including leaves to branch weight including leaves = 0.00496). Due to these variations, some further assessment of a standard alder tree being added to the ponds are made.

The surface area of the branch bundles used as substrate (including leaves), described above, was carefully measured. The branches were part of a tree chosen by Bill Jones as representative of trees placed in PP10 to PP13 in 1993 and 1994. A branch surface area to weight ratio for branches with leaves used in the branch bundle was 0.00496 $m^2.g^{-1}$. A lower value (without leaves) of 0.000661 $m^2.g^{-1}$, would apply to alders added to PP11, 12 and 13, as these trees were cut in winter.

The 1994 estimate of branch area per unit weight (0.000661 $m^2.g^{-1}$) is lower than the 1989 estimate (0.00272 $m^2.g^{-1}$). The size of the trunk of a particular alder greatly adds to the weight, but not to the surface area, of the tree. Perhaps the 1989 tree had a relatively short, low diameter trunk, compared to the 1994 tree (Table 6).

Alder substrate has been used as the material supporting algal biomass growth. As an alternate, non-biodegradable material, fish netting, may be a more practical choice as a growth substrate for biological polishing in the OWP.

Along a string, alder branch bundles and fish netting over a given area were suspended Ponds 10, 11, 12 and 13, and in the OWP and OEP. The growth on the netting frames (periframes) was much higher than on the alder branches, when the actual surface areas are compared. On average, the periphyton-precipitate build- up on the periframes was 14.4 $g.m^{-2}$ actual netting surface $area.d^{-1}$, compared to 2.5 $g.m^{-2}$ on actual branch and leaf surface $area.d^{-1}$ (Table **6a).**

The cost and efficiency of using netting versus branches was evaluated. It was concluded, that although netting is more expensive to install, the longevity is likely higher. A further advantage is that netting likely provides more surface area for biomass growth.

3.4.5 Water Quality in Low Versus High Turnover Areas of PP10 to PP13

A sampling program was carried out to determine if indeed the presence of algal biomass and brush in the pool areas, would have a direct effect on the water quality. Water samples were collected from among brush and in open areas in the Polishing Pond system. Overall, it appears that both total suspended solids and zinc concentrations are typically lower among brush ([Zn], 4.84-11.3 $mg.L^{-1}$, [TSS], 2.3-6.5 $mg.L^{-1}$) than in open areas with relatively high flow-through ([Zn], 10.55-12.9 mgL^{-1}, [TSS], 5.7-8.3 $mg.L^{-1}$; Table 7). .Oxygen concentrations were also higher among brush, where periphyton density and oxygen production is high. These data do suggest, that the distribution of the growth substrate in the pond is a contributing factor to the efficiency of zinc removal.

3.4.6 Polishing Ponds 1 to 6 Sediment Characteristics

Sediment samples were collected from Polishing Pond 1 and 6. Of primary interest is the content, chemical form and stability of iron in these sediments. Data concerning Polishing Ponds 1 through 6, including sediment thickness, approximate sediment wet weight and dry weight and elemental composition, have been determined for each pond before they were destroyed during construction in mid-August, 1994.

Wet weight, dry weight, percent water and percent loss on ignition were measured for 17 sediment samples collected from Polishing Ponds 1 to 6 prior to their decommissioning. The results are given in Table 8.

Overall, sediment samples collected by ASARCO contained less water (low % water) and low organic content (% LOI), compared to samples collected by Boojum. The

ASARCO samples contained a much higher fraction of clay. Boojum samples concentrated on the iron hydroxide layer which was about 6 to 8 cm thick in pond 1 and 3 to **4** cm thick in pond 6. In Table **9,** the elemental composition of the sediment is presented. The analysis confirms the zinc removal process, in that zinc concentrations and iron concentrations are very high with 3% to 8 **%** zinc and **2 %** to 19 **%** iron. These concentrations are in the same range as those determined for the algal biomass.

4.0 VEGETATING POLISHING POND BERMS AND FLOATING CATTAILS

4.1 Berm Seeding with Sedges

In June, 1992, revegetation plots were set up on an embankment of Polishing Pond 2 using *Scirpus atrocinctus* seeds collected in the Buchans vicinity in fall, 1991 (Schematic 2a). Seeds germinated and a dense *Scirpus* population still covers those plots where Nutricote fertilizer was added.

Nutricote fertilizer, by weight, is approximately four times as expensive as regular fertilizer. In addition, collection of *Scirpus* seeds is an added labour component, compared to purchasing commercial seed mixes. Therefore, in June 1994, a large-scale seeding experiment was set up on Polishing Ponds 10, 11 and 12 berms, with treatments using both a commercial seed mix and *Scirpus* seeds, and both Nutricote and regular fertilizer (Schematic 2b). The effectiveness of the various treatments and their associated costs can be assessed at the end of the growing season, in terms of percent plant cover.

A commercial seed mix and Nutricote or regular fertilizer was added to plots #1 through #49. Eleven 10 m^2 plots had been set up along the north-east berm of Polishing Pond 12 and were designated as *Scirpus* plots (Schematic 2b). The plots were raked with a stiff tined rake before planting *Scirpus atrocinctus* seeds collected from the Buchans area in November 1991.

To two of the plots (#53, #57), 0.2 kg of 17-17-17 fertilizer was added. To another three of the plots (#50, #54, #58), 0.1 kg of 17-17-17 fertilizer and 0.1 kg of Long harbour sand were added. To another three plots (#51, #55, #59) 0.1 kg of 14-14-14 Nutricote were added and to the final three plots (#52, #56, #60), 0.2 kg of Nutricote were added.

Plastic bags containing 40 g (dry weight) of *Scirpus* seeds were pre-soaked with tap water for 36 hrs. These packets of soaking seeds were placed on the berm and exposed to sunlight in late afternoon until the next morning. The moist seeds were then mixed with 5 L of Pigeon Inlet soil and the mix was distributed over the plots.

To a twelfth plot (#49), 0.2 kg of 17-17-17 fertilizer was added and 40 L of Pigeon Inlet soil was distributed. No *Scirpus* seed was planted.

As the plots were set up relatively late in the season, the growth of these plots was not easily assessable by September 1994. Results have to be assessed in 1995.

4.2 The OEP Floating Cattail Rafts

Floating cattail mats are found in nature, as documented by Hogg and Wein (1987). These workers determined that entrapment of gas within the root, rhizome and organic layer is the major contributor of buoyancy to the floating cattail mat (Schematic 2b).

During the July, 1994 site visit, square blocks (30 x 30 cm) of the 1990, 1991 and 1993 *Typha angustifolia* plants grown from seed were cut from the surrounding populations. Both the 1990 and 1991 blocks freely floated without the support of the rafts or surrounding population. This is in contrast with the same procedure done in June 1992, when the blocks sank upon cutting. This test indicates that the 1990 and 1991 populations are now buoyant, independent of the flotation structures.

The three plots were separated into green shoots, litter, rhizomes and roots and are drying in the hoist building. When dry, the components will be weighed and the above and below ground biomass per unit area calculated, for comparison to previous determinations (Table 10).

5.0 CONCLUSIONS

The connection of the effluents from the OEP, OWP and the Drainage Tunnel appears to have resulted in an option which allows in the polishing ponds for a significant reduction of the zinc loading to the Buchans River. The performance of the scaled-up polishing ponds suggests that the design criteria are correct, and if operated within the recommended retention time, the performance is satisfactory.

The chemical conditions of the Lucky Strike gloryhole should be evaluated with respect to the establishment of a chemocline. Such a development could be detrimental in the long term, if the pit turns over every year. This has been observed in other flooded pits in northern Saskatchewan.

6.0 RECOMMENDATIONS

The proposal for 1995 will address four aspects:

1. Define the long-term zinc removal capacity of the Drainage Tunnel-OWP-OEP-Polishing Pond system along with the sediment accumulation rate.

2. Assess the long-term trends of the effluents from all relevant parts of the waste management area to confirm the present understanding of the performance of the zinc removal processes.

3. Develop measures for the OWP which will enhance biological polishing.

4. Assess Lucky Strike chemocline and potential annual turnover of pit volume.

Table 1: Water Quality of Waste Rock Pile Seepage and Ponds.

Date Sampled		Flow (L/s)	POND 7, SEEPAGES AND DITCH pH	Cond (uS/cm	Em (mV)	Acidity (mg/L	Al (mg/L	Fe (mg/L)	Cu (mg/L	Zn (mg/L	POND 8 Flow (L/s)	pH	Cond (uS/cm	Em (mV)	Acidity (mg/L	Al (mg/L	Fe (mg/L	Cu (mg/L	Zn (mg/L	POND 9 pH	Cond (uS/cm	Em (mV)	Acidity (mg/L	Al (mg/L	Fe (mg/L	Cu (mg/L	Zn (mg/L
26-Jul-89	Centre		3.29	1400			18	2.1	3.3	101		3.43	1450			7.8	5.7	0.2	34	3.44	1500			8.2	5	0.2	35
08-Aug-89	Inflow	0.22	3						2.22	78.15																	
	Outflow																			3.4						0.77	36.55
12-Sep-89	Inflow	0.22	3.2	2000					1.51	60.2																	
	Outflow																			3.6	1500					0.13	1.005
26-Sep-89	Inflow	0.13	3.2	1000					1.21	50.35																	
	Outflow																			3.4	650					0.11	5.15
04-Oct-89	WRP Seep		3.6	1400			21	1	4.1	24																	
	Inflow		3.37	800			11	6.7	2.6	72																	
	Centre		5.4	700			0.8	5.1	0.2	1.6		4.8	650			3	7.3	0.07	24	3.6	700			9.5	12	0.07	39
	Outflow		3.8	800			9.6	8.1	0.6	53										4.8	600			10	14	0.05	23
09-Oct-89	Inflow	0.32	3.2	950					1.925	52.1																	
	Outflow																			3.4	975					0.1	14.15
08-Nov-89	Inflow	0.19	3.4	790					2.56	74.85																	
	Outflow																			3.6	770					0.24	70.95
11-Jun-90	Centre																			4.5		(Pond Clou		1.5	4.9	0.1	1.1
25-Jul-90	Inflow		3	1490	310		8.9	4.6	2.4	65																	
	In Sed		5.06	1100	-230		0.5	4.9	0.05	4.3		3.06	1140	-41		10	6.6	0.02	36	5.86	900	-339		0.1	0.1	<0.01	0.2
	Outflow											2.84	1000	217		5.7	2.7	0.5	37	2.82	900	150		3.8	1.5	0.05	25
06-Sep-90	Inflow	0.19	3.4	1250					0.22	8.43																	
	Outflow																			3.7	800					0.095	2.225
05-Nov-90	Inflow	0.25	3.4	1250					0.22	8.43																	
	Outflow																			3.6	500					1.085	47.95
20-May-91	Inflow		3.4	600					2.365	38.66																	
	Outflow																			3.7	445					0.485	17.68
05-Jul-91	Inflow		3.46	1520	458							3.49	497	461						3.64	1077	400					
	Centre		3.54	1353	436							3.55	1232	400						3.59	985	350					
	In Sed		3.49	1257	-6							3.75	1028	394						3.59	989	423					
	Outflow											3.44	1326	417													
25-Jul-91	Inflow		3.2	1375					2.55	84.95																	
	Outflow																			3.5	1100					0.09	11.94
23-Aug-91	Inflow		3.54	990	300	382	14	<1	2	105																	
	In Sed		3.65	1030	242	385	19	<1	<1	68		3.62	910	34	239	11	<1	<1	26	3.72	800	104	123	3	<1	<1	21
	Outflow																			3.8	780	245	147	2	<1	<1	29
04-Oct-91	Inflow		3.1	1600					2.365	38.66																	
	Outflow																			3.5	1175					0.52	27.26
17-Oct-91	Inflow		3.31	1700	471		29	2.3	3.14	127		3.47	1500	453		26.5	3.2	1.56	123	3.73	1000	448		14.3	2	0.64	56
	In Sed		3.44	1600	368		27	5.1	0.28	182		4.01	1100	163		16.1	13.6	0.15	13	3.75	900	253		14	2.9	0.6	31.3
15-Nov-91	Inflow		3.3	850					3.98	107.8																	
	Outflow																			3.5	450					1.205	49.45
31-May-92	Seepage		3.22	1090	439																						
	Inflow		3.53	990	398																						
	Outflow		3.35	940	381							3.71	770	383						3.83	690	381					
19-Aug-92	Inflow	0.63	3	(samples sent to Boojum)																							
	Outflow																			3.3							
29-Aug-93	New Ditch Begin		4.04	1220	309	422.2																					
	New Ditch End		3.82	1180	323	121.8																					
	In		3.19	1650	385	474						3		421													
	Centre																			3.2	1170	319	144.5				
	Outflow		3.1	1280	399	431						3.15	1300	374	217												
13-Jul-94	Inflow	<0.1	3.12	1460	328	328				66.87																	
	Centre																			4.37	1410	217	132.1				33.4
	Outflow	0.2	3.04	1500	373	298				55.4	0.6	3.17	1410	274	243.1				35.05								

Table 2: Water Samples Collected During July 10-15, 1994 Buchans Site Visit.

Date	Sampling Location	pH	T C	Cond	Em	Acidity	[Zn], mg/L	L/min
13-Jul-94	WRP-A	3.29	25.5	1700	284	697.2	89.15	2.1
13-Jul-94	WRP-B	3.75	20.2	1300	224	309.6	46.355	12.0
13-Jul-94	WRP-C	3.7	23.8	1150	235	187.5	38.6	0.6
13-Jul-94	WRP-D	3.31	26.8	1980	294	591.9	104.55	<0.1
13-Jul-94	WRP-E	2.85	27.3	2280	357	501.5	80.85	<0.1
13-Jul-94	WRP-F	4.43	23.7	1400	203	110.4	33.4	15.0

Table 3: OWP and OEP water chemistry, July 10-15, 1994.

Date	Area	Sampling Location	Vertical	pH	T C	Cond uS/cm	Em mV	Acidity mg/L	Alkalinity mg/L	[Zn] mg/L
11-Jul-94	OWP	Centre	Surface	6.53	17.4	820	148	35	59	17
11-Jul-94	OWP	Centre	6 m	5.91	5.6	640	54	168	50	21
11-Jul-94	OWP	Centre	Bottom(42')	6.07	6.5	680	73	226	40.9	23
11-Jul-94	OWP	Old Curtain	Surface	6.29	17.9	810	35	34	57	17
11-Jul-94	OWP	Old Curtain	Bottom	6.12	7.6	620	31	144	64	20
11-Jul-94	OWP	New Curtain	Surface	6.62	18	760		32	53	16
11-Jul-94	OWP	New Curtain	Bottom	6.43	6.3	680	-90	197	54	18
11-Jul-94	OWP	D.T. @ OWP	Surface	5.78	7.1	245	125	36	25	15
15-Jul-94	OWP	Centre	Surface	6.76	16.3	700	35	47	57	
15-Jul-94	OWP	Centre	6 m	6.05	6.6	640	8	207	51	
15-Jul-94	OWP	Centre	Bottom(42')	6.05	8.2	690	-1	235	49	
11-Jul-94	OEP	Centre	Surface	6.51	18.7	1520	10	35	158	14
11-Jul-94	OEP	Centre	2.5 m	6.45	13.7	1730	-100	176	220	18
11-Jul-94	OEP	Centre	Bottom	6.51	12.6	2110	-150	510	368	22
11-Jul-94	OEP	At Weir	Surface	7.16	18.4	1510	56	43	166	14

Table 4: Polishing Ponds 1 to 6 water chemistry, July 12, 1994.

Date	Area	Sampling Location	pH	T C	Cond	Em	Acidity	Alkalin	[Zn], mg/L	L/min
12-Jul-94	Pol Ponds	PP1 In	7.23	19.3	1480	109	40.7	149.9	11.85	
12-Jul-94	Pol Ponds	PP1 Out	7.34	17.7	1410	106	25.3	145.9	8.75	8.6
12-Jul-94	Pol Ponds	PP2 Out	7.28	18.5	1405	105	15.1	129.8	6.87	8.0
12-Jul-94	Pol Ponds	PP3 Out	7.28	18.8	1390	106	10.7	123.2	5.195	5.5
12-Jul-94	Pol Ponds	PP4 Out	7.18	19.8	1380	102	4.5	112.2	3.74	6.0
12-Jul-94	Pol Ponds	PP5 Out	7.12	19	1350	109	5.9	106	3.215	6.0
12-Jul-94	Pol Ponds	PP6 Out	7.03	18.3	1310	110	7.5	95.3	2.45	6.0

Table 5a: Summary of Buchans polishing Pond Periphyton Data, 1993.

Sample Location	Treatment	Date Placed	Date Retrieved	Time in Situ (d)	Percent Cover	Dry Wt (g)	Substrate Area (m2)	Growth g/m2/day	L.O.I. %	Branch Wt (g)
PP 10	Peri-Net - #10+Fert	20-Jul-93	30-Aug-93	41	20%	2.205	0.130 *	0.413	31	
PP 10	Peri-Net - P 10 #11	20-Jul-93	30-Aug-93	41	25%	9.508	0.130 *	1.781	21	
PP 6	Peri-Net - P 6 1of 6	20-Jul-93	30-Aug-93	41	80%	5.432	0.130 *	1.018	34	
PP 6	Peri-Net - P 6 2 of 6	20-Jul-93	30-Aug-93	41	22%	1.597	0.130 *	0.299		
PP 6	Peri-Net - P 6 6 of 6	20-Jul-93	30-Aug-93	41	70%	5.490	0.130 *	1.028	23	
PP 1	Peri-Net - P 1 5 of 6	20-Jul-93	30-Aug-93	41	82%	3.005	0.130 *	0.563	32	
Pp 1	Peri-Net - P 1 3of 6	20-Jul-93	30-Aug-93	41	32%	1.435	0.130 *	0.269		
PP 1	Peri-Net - P 1 4 of 6	20-Jul-93	30-Aug-93	41	35%	1.760	0.130 *	0.330		
PP 10	Peri-Net - P10 #1	20-Jul-93	30-Aug-93	41	40%	6.082	0.130 *	1.139	30	
PP 10	Peri-Net - P10#3+Fert	20-Jul-93	30-Aug-93	41	5%	6.483	0.130 *	1.214	29	
PP 10	Peri-Net - P10 # 7	20-Jul-93	30-Aug-93	41	2%	2.943	0.130 *	0.551	35	
PP 10	Peri-Net - P10 # 2	20-Jul-93	30-Aug-93	41	25%	5.665	0.130 *	1.061	32	
							Average	0.806	g/m2/day	
PP 6	Jelly - PP # 6 Alga	01-Sep-89	30-Aug-93	1459	100%	22.000	0.015 **	1.027	31	5.4
PP 10	Jelly - PP 10 Algae	01-Nov-92	30-Aug-93	302	100%	30.100	0.051 **	1.949	27	18.8
PP 1	Jelly - PP 1 Algae	01-Sep-89	30-Aug-93	1459	100%	71.700	0.064 **	0.769	18	23.5
							Average	1.248	g/m2/day	

Table 5b: Summary of Buchans polishing Pond Periphyton Data, 1994.

PP10	Branch Bundle	14-Jul-94	17-Aug-94	34	100%	18.000	0.212 ***	2.493		42.8 #
PP10	Branch Bundle	14-Jul-94	17-Aug-94	34	100%	14.000	0.212 ***	1.939		42.8 #
PP10	Branch Bundle	14-Jul-94	17-Aug-94	34	100%	29.000	0.212 ***	4.017		42.8 #
PP10	Branch Bundle	14-Jul-94	17-Aug-94	34	100%	39.000	0.212 ***	5.402		42.8 #
PP10	Branch Bundle	14-Jul-94	17-Aug-94	34	100%	17.000	0.212 ***	2.355		42.8 #
OEP	Branch Bundle	18-Jul-94	06-Sep-94	50	100%	27.300	0.212 ***	2.571		42.8 #
OWP	Branch Bundle	18-Jul-94	06-Sep-94	50	100%	23.600	0.212 ***	2.223		42.8 #
PP11	Branch Bundle	18-Jul-94	06-Sep-94	50	100%	21.200	0.212 ***	1.997		42.8 #
PP12	Branch Bundle	18-Jul-94	06-Sep-94	50	100%	10.200	0.212 ***	0.961		42.8 #
PP13	Branch Bundle	18-Jul-94	06-Sep-94	50	100%	13.800	0.212 ***	1.300		42.8 #
							Average	2.526	g/m2/day	
OWP	Jelly	01-Sep-89	13-Jul-94	1776	100%	15.105	0.037 **	0.228		13.7
PP1	Jelly	01-Sep-89	13-Jul-94	1776	100%	19.346	0.019 **	0.563		7.1
PP10	Jelly	01-Nov-92	13-Jul-94	619	100%	10.152	0.047 **	0.350		17.2
PP11	Jelly	01-Jan-94	13-Jul-94	193	100%	1.698	0.084 **	0.105		30.8
PP12	Jelly	01-Jan-94	13-Jul-94	193	100%	2.752	0.153 **	0.093		56.1
PP13	Jelly	01-Jan-94	13-Jul-94	193	100%	0.305	0.075 **	0.021		27.5
PP2	Jelly	01-Sep-89	13-Jul-94	1776	100%	18.884	0.014 **	0.761		5.1
PP3	Jelly	01-Sep-89	13-Jul-94	1776	100%	18.353	0.016 **	0.637		6.0
PP4	Jelly	01-Sep-89	13-Jul-94	1776	100%	30.924	0.017 **	1.024		6.3
PP5	Jelly	01-Sep-89	13-Jul-94	1776	100%	28.074	0.028 **	0.567		10.3
PP6	Jelly	01-Sep-89	13-Jul-94	1776	100%	23.408	0.020 **	0.655		7.4
							Average	0.455	g/m2/day	
PP10	Periframe	14-Jul-94	17-Aug-94	34	100%	10.000	0.040 ****	7.429		
PP10	Periframe	14-Jul-94	17-Aug-94	34	100%	27.000	0.040 ****	20.059		
PP10	Periframe	14-Jul-94	17-Aug-94	34	100%	42.000	0.040 ****	31.203		
PP10	Periframe	14-Jul-94	17-Aug-94	34	100%	25.000	0.040 ****	18.573		
PP10	Periframe	14-Jul-94	17-Aug-94	34	100%	24.000	0.040 ****	17.830		
OEP	Periframe	18-Jul-94	06-Sep-94	50	100%	18.000	0.040 ****	9.093		
OWP	Periframe	18-Jul-94	06-Sep-94	50	100%	19.700	0.040 ****	9.952		
PP11	Periframe	18-Jul-94	06-Sep-94	50	100%	31.000	0.040 ****	15.661		
PP12	Periframe	18-Jul-94	06-Sep-94	50	100%	20.500	0.040 ****	10.356		
PP13	Periframe	18-Jul-94	06-Sep-94	50	100%	7.100	0.040 ****	3.587		
							Average	14.374	g/m2/day	

* Perinets 0.31m x 0.21 m, 2 layers

** 1989 estimate used: 0.00272 m2/g (dry) branch

*** 1994 estimate used: 0.004961 m2/g (dry) branch

**** Periframes 0.3 m x 0.3 m, 0.44 m2 S.A. per m2 netting

Standard 1994 Branch Bundle unit weight used; individual weights not available.

Table 6: 1994 "Standard" Buchans Alder Tree Dimensions.

WHOLE TREE	Weight (g)	SUBSAMPLE - 5 branch bundle Weight (g)			Surface Area (m2)	WHOLE TREE	Surface Area (m2)		
Leaves	115.3	9.9	123	leaves	0.237		2.760		
Branches (0.01-0.7 cm diameter)	228.4	32.9			0.044		0.305		
Trunk (0.7 - 2.6 cm diameter)	298.2	298.2			0.120		0.120		
Whole Tree	641.9					Whole Tree	3.184	m2/standard tree	
						or	0.004961	m2/g	with leaves
							0.000661	m2/g	without leaves
							0.00272	m2/g	1989 estimate

Table 6a: Comparison of costs of using Alder brush versus nylon netting as growth substrate for algae.

	NETTING		ALDER TREES	
			$3,659.00	per 15,000 alders
			3.6	Alders per m3 of water
			0.6419	kg per tree
@ $308/50 lb	$12.10	per kg of netting, before tax	$0.38	per kg of tree
	1.689	m2 netting per kg		
	0.743	m2 of actual S.A. per kg of netting	0.661	m2 of actual S.A. per kg of tree
Growth	14.374	g periphyton /m2 actual S.A./day	2.526	g periphyton /m2/day
	20	year working life (at least)	10	year working life (at most)
@ 200 days/yr	42,721	g periphyton/kg netting in working life	3,340	g periphyton/kg alder in working life
			$0.11	per kg of periphyton over 10 years
	$0.28	per kg of periphyton over 20 years	$0.23	per kg of periphyton over 20 years

Table 7: Water quality in polishing ponds: inflow, open water and among brush, September, 8, 19

Pond	Area	[Zn] mg/l	Vol, L	F.P. cak (g)	T.S.S mg/l	T C	pH	Em	surface [O2] from	to	bottom [O2]
PP10	IN	12.76	0.15	0.00079	5.3		7.11	-20			
PP10	OPEN	12.85	0.15	0.00086	5.7						
PP10	BRUSH	4.84	0.25	0.00133	5.3		6.63	-44			
PP11	OPEN							11	9.07	10.5	
PP11	BRUSH	15.26	0.25	0.00058	2.3	14.1		30	9.76		
PP12	OPEN	12.75	0.15	0.00116	7.7			38	9.8	11	
PP12	BRUSH	11.3	0.15	0.00097	6.5			30	16.4		
PP13	OPEN	10.55	0.15	0.00124	8.3			-11	9.8		11.4
PP13	BRUSH	8.755	0.15	0.00097	6.5			-31	12.2	14.2	

Table 8: Characteristics of Polishing Pond sediments collected August 17 and September 8, 1994.

Pond	Location	Date Collected	Wet Vol. (mL)	Wet Wt. (g)	Shipped Wt. (g)	Boojum Wt (g)	Dry Wt. (g)	% water	% LOI
PP1	Middle	17-Aug-94		518	500	498	398	23%	2.7
PP1	Side	17-Aug-94		528	505	497	358	32%	5.1
PP2	Middle	17-Aug-94		571	540	528	429	25%	1.9
PP2	Side	17-Aug-94		559	538	530	431	23%	3.4
PP3	Middle	17-Aug-94		582	552	547	445	24%	1.7
PP3	Side	17-Aug-94		544	520	514	375	31%	2.5
PP4	Middle	17-Aug-94		544	520	519	371	32%	4.3
PP4	Side	17-Aug-94		575	547	537	305	47%	6.6
PP5	Middle	17-Aug-94		562	525	517	418	26%	1.9
PP5	Side	17-Aug-94		565	540	554	384	32%	6.4
PP6	Middle	17-Aug-94		556	528	513	435	22%	3.9
PP6	Side	17-Aug-94		549	520	510	375	32%	3.5
PP1	1	08-Sep-94	710	791			153	81%	11.1
PP1	2	08-Sep-94	900	1038			214	79%	6.6
PP6	1	08-Sep-94	1035	1355			683	50%	11.8
PP6	2	08-Sep-94	870	980			185	81%	17.6
PP1	Bottom	09-Sep-94		746		202	200	73%	6.45

Table 9: Elemental composition of Polishing Ponds 1 and 6 sedime

Location	Polishing Pond 1	Polishing Pond 1	Polishing Pond 6	Polishing Pond 6
Date	17-Aug-94	17-Aug-94	01-Sep-94	01-Sep-94
Sampler	ASARCO	BRL	ASARCO	BRL
In ug/g Al	6,560	9,650	6,990	9,240
Ba	51	368	29	132
Cu	13	375	10	62
Fe	7,380	195,000	6,310	25,500
Pb	38	791	22	96
Mn	104	2,030	286	2,210
Ni	1	14	2	12
Zn	187	30,200	714	8,020
% L.O.I.	2.7	11.1	3.9	11.8

Table 10: Buchans Cattails - 1994 Biomass Data

Location	OEP Second Yr	OEP Fourth Year	OEP Fifth year
Date Transplanted	02-Aug-93	26-Jul-91	26-Jul-90
Date Sampled	12-Jul-94	12-Jul-94	12-Jul-94
n=	1	1	1
Treatment at Transplant	Nutricote+ Bonemeal	Nutricote+ Bonemeal	Nutricote+ Bonemeal
Fruits	218	180	0
Green+Brown leaves	2912	2409	1617
Old Rhizomes	339	283	121
New Rhizomes	604	940	1484
Old+New Roots	1058	1038	267
Leaf Litter	318	201	236
TOTAL BIOMASS, g/m2	5449	5051	3725

Fig. 1: OEP Outflow Zinc Concentrations
Jan. 13, 1989 to Dec. 25, 1994

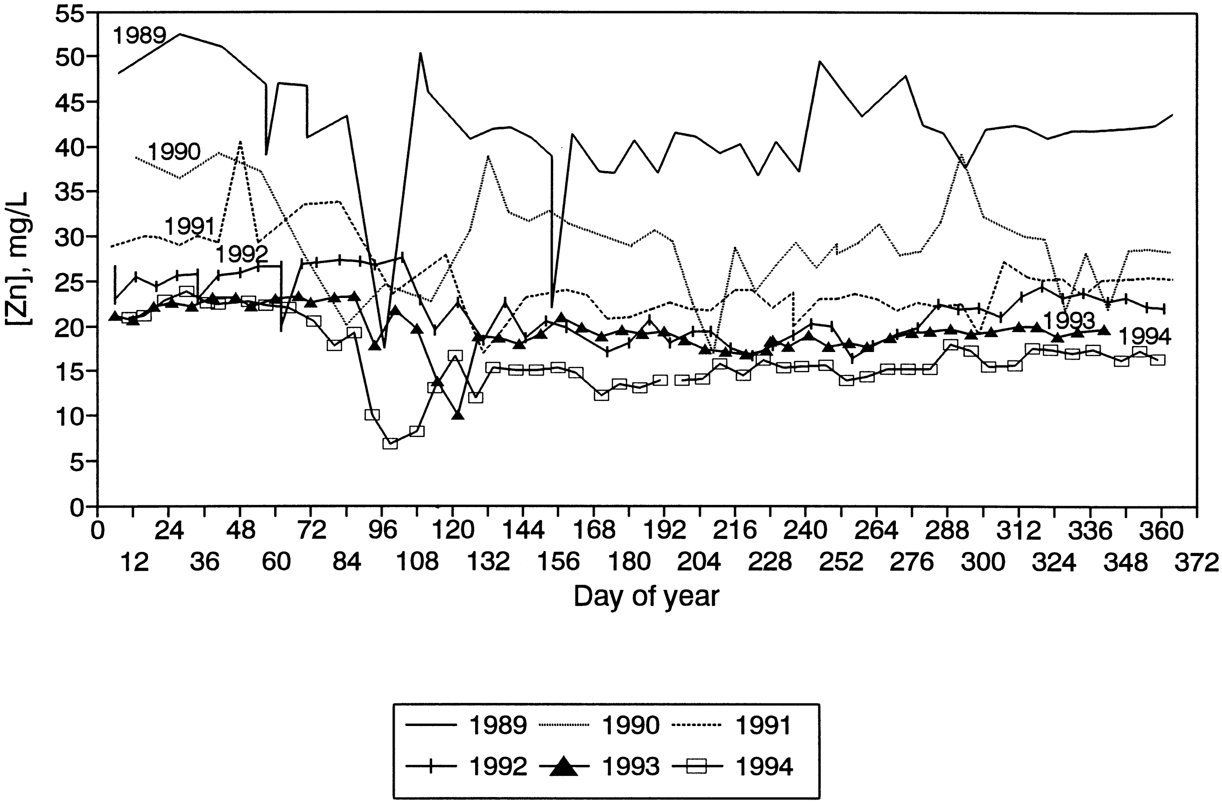


Fig. 2: OEP Outflow, L/s
Jan. 13, 1989 to Dec. 7, 1993

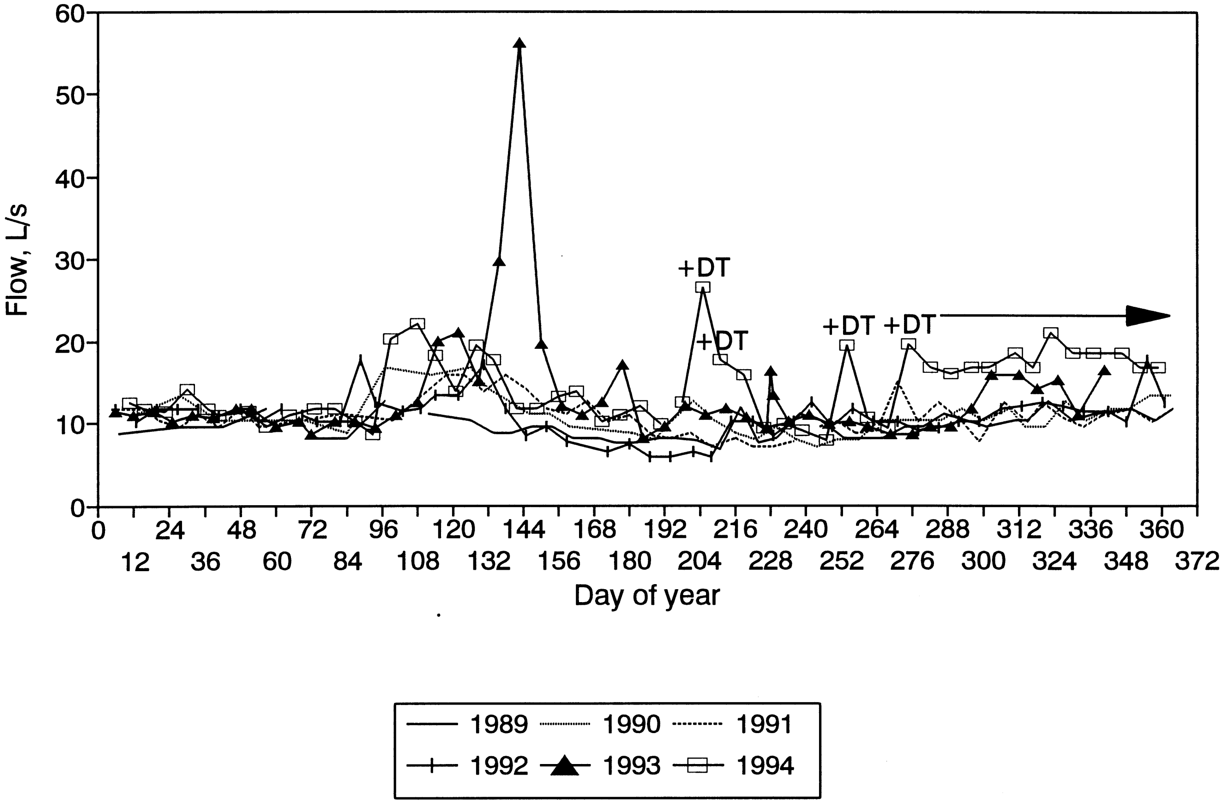


Fig. 3: OEP Average [Zn]
Annual: Jan. 13, 1989 to Dec. 25, 1994

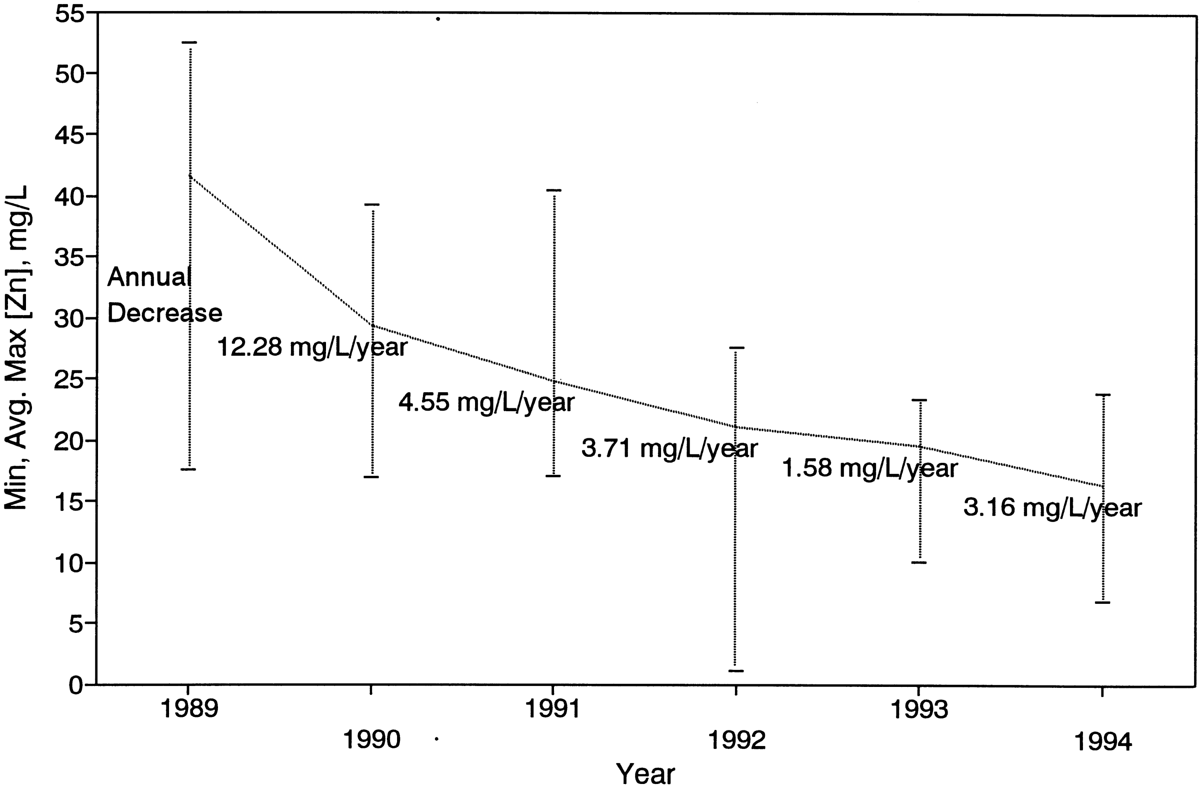


Fig. 4: OWP Zinc Concentrations
Mar. 2, 1989 - Dec. 3, 1994

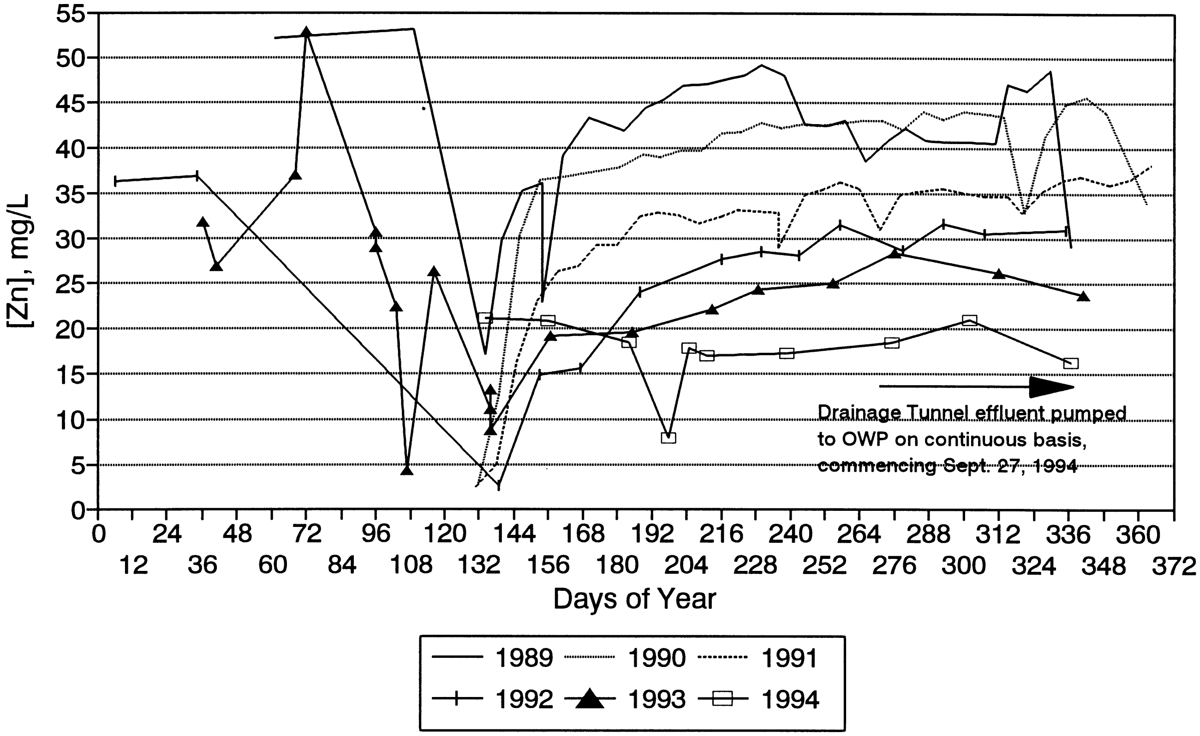


Fig. 5: OWP Average [Zn]
Annual: Mar. 2, 1989 - Dec. 3, 1994

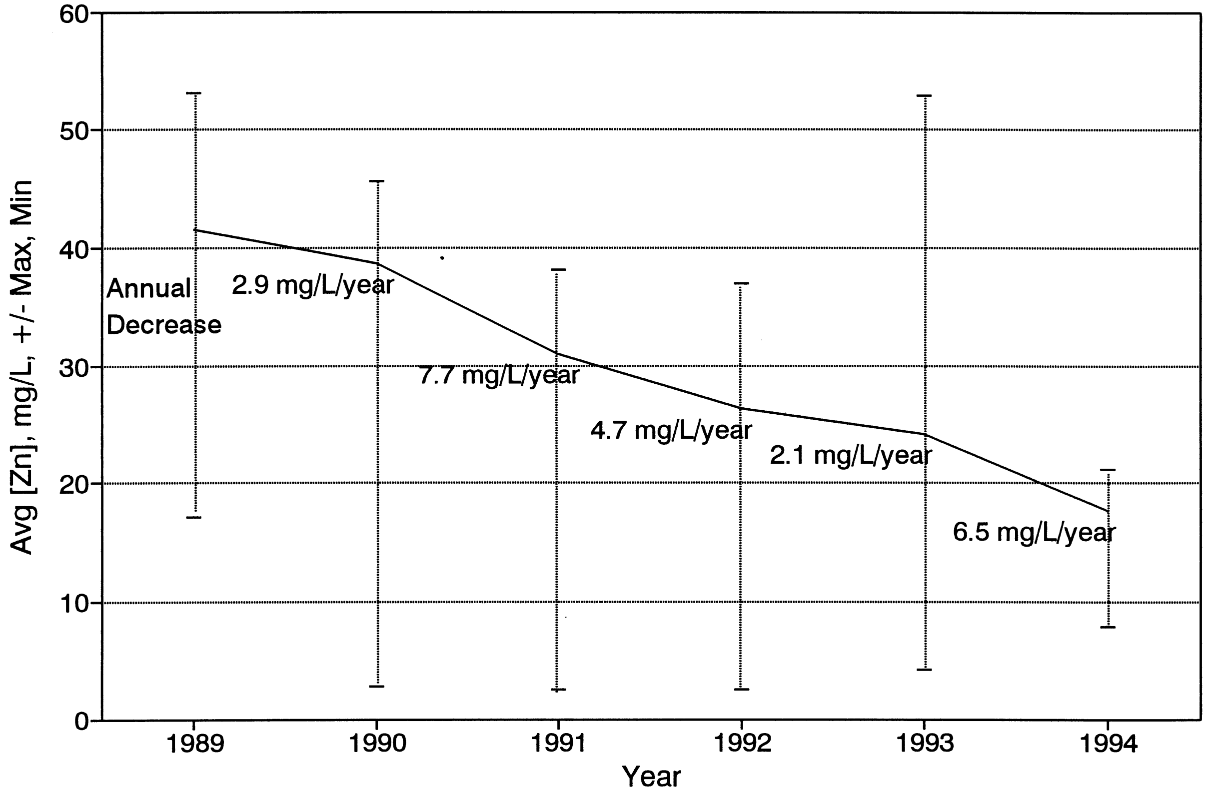


Fig. 6: OWP Zinc Concentrations
March/April 1988,1989,1991,1993,1994

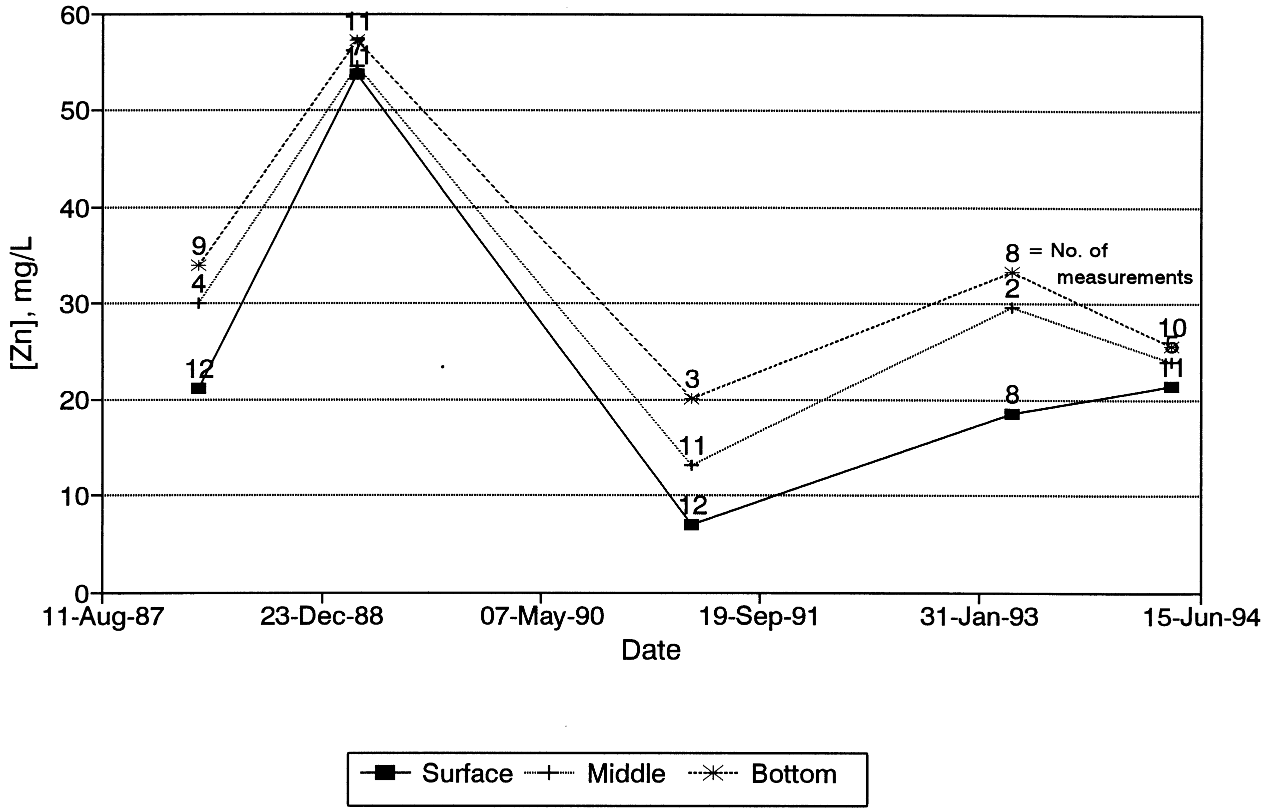


Fig. 7:Drainage Tunnel Zn Concentration
Jan 13, 1990 - Dec. 25, 1994

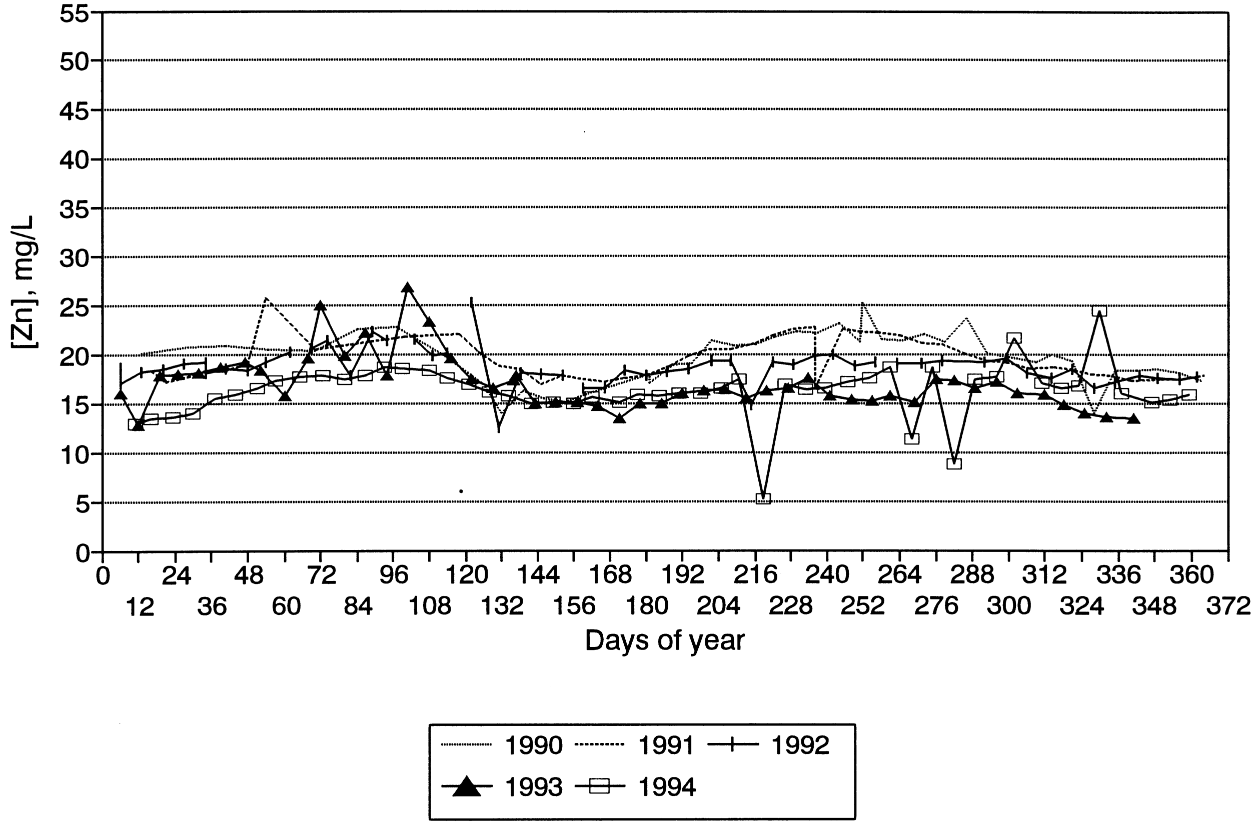


Fig. 8: Drainage Tunnel Flow
Jan 13, 1990 - Dec. 25, 1994

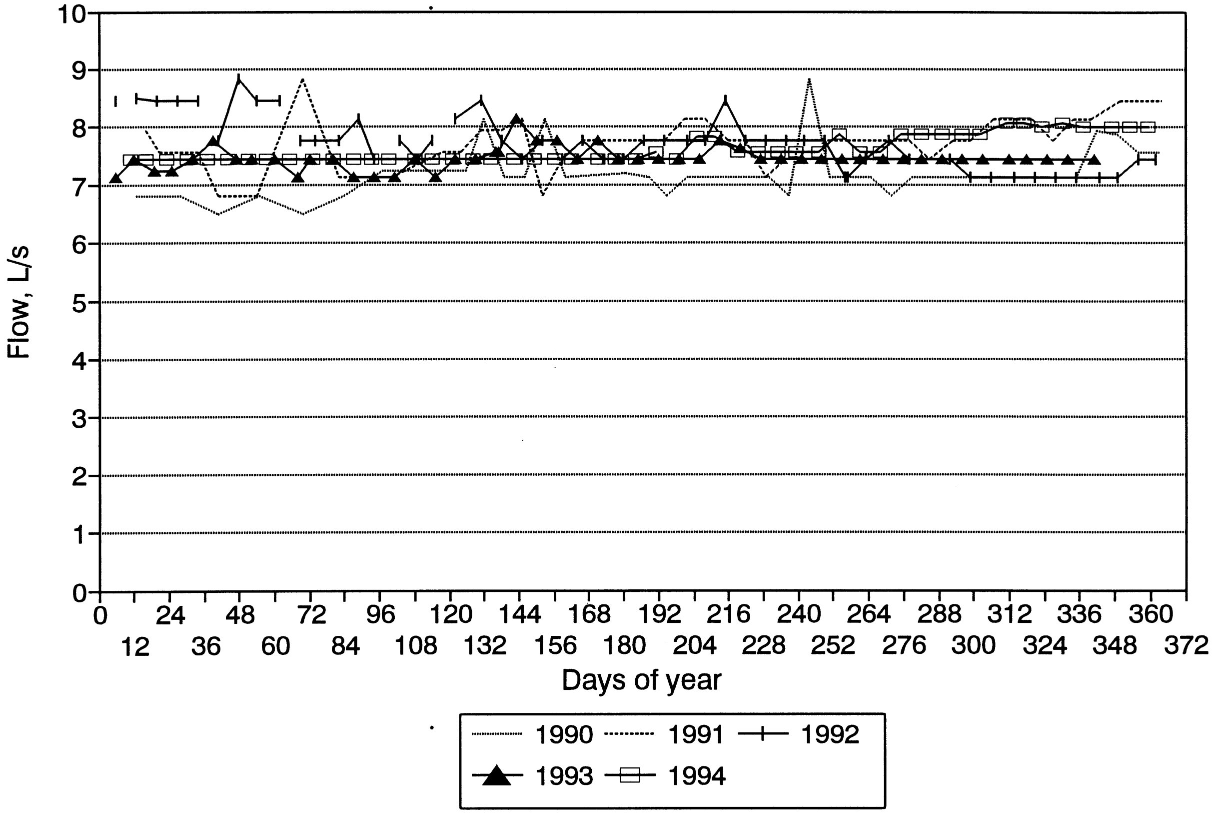


Fig. 9: Drainage Tunnel Average [Zn]
Annual: Jan 13, 1990 - Dec. 7, 1993

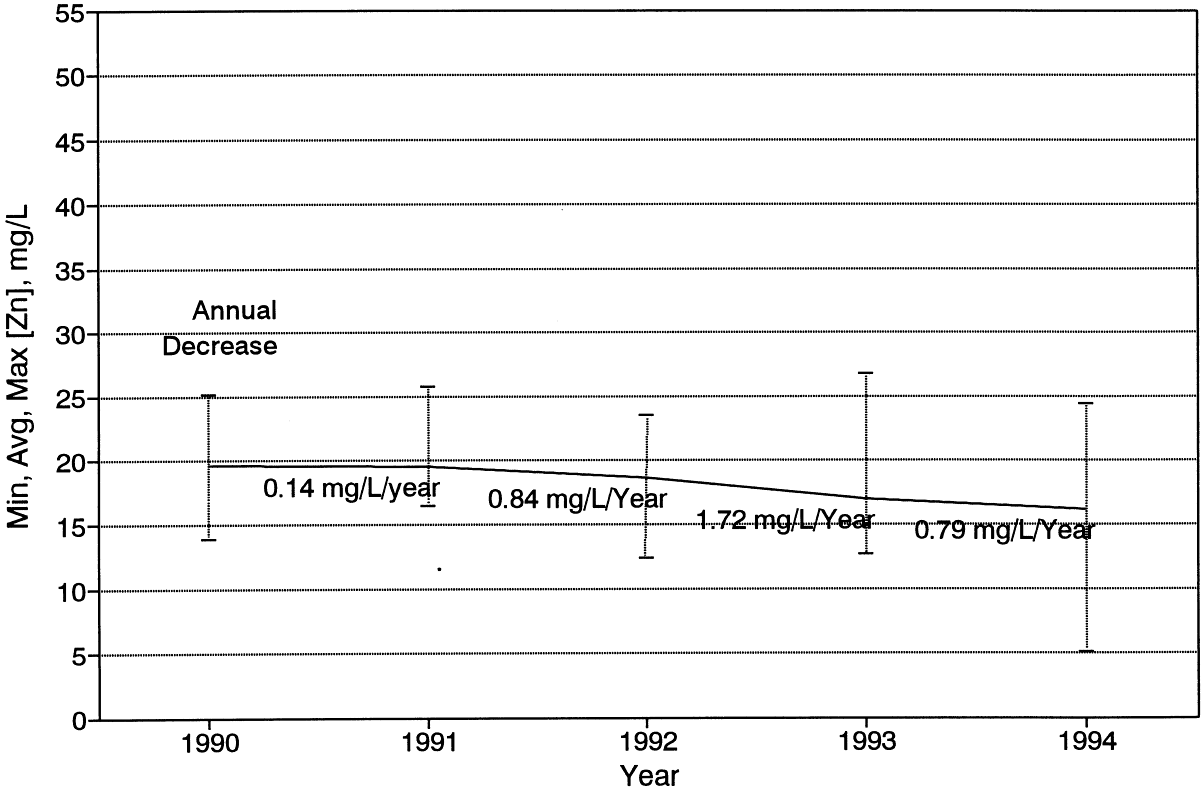


Fig. 10: WRP ARUM Ponds 7 and 9
Zinc Concentrations, 1989 - 1994

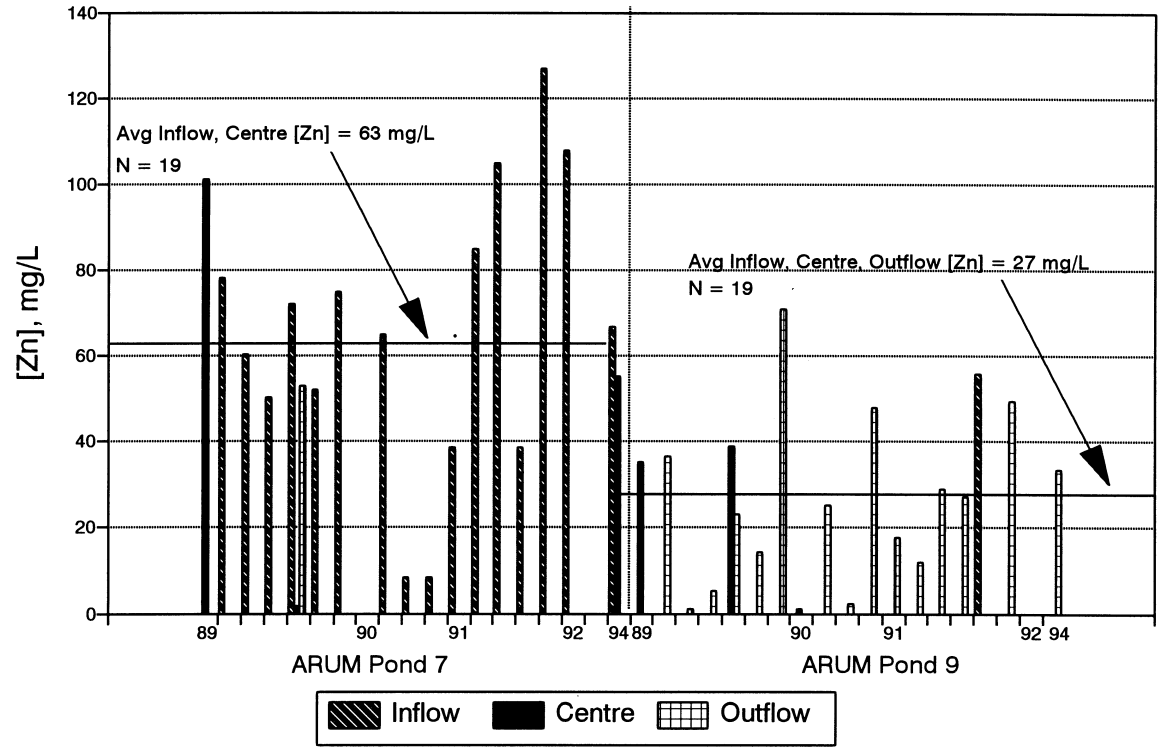


Fig. 11: Lucky Strike Zn Concentrations
Apr. 10, 1990 - Dec. 3, 1994

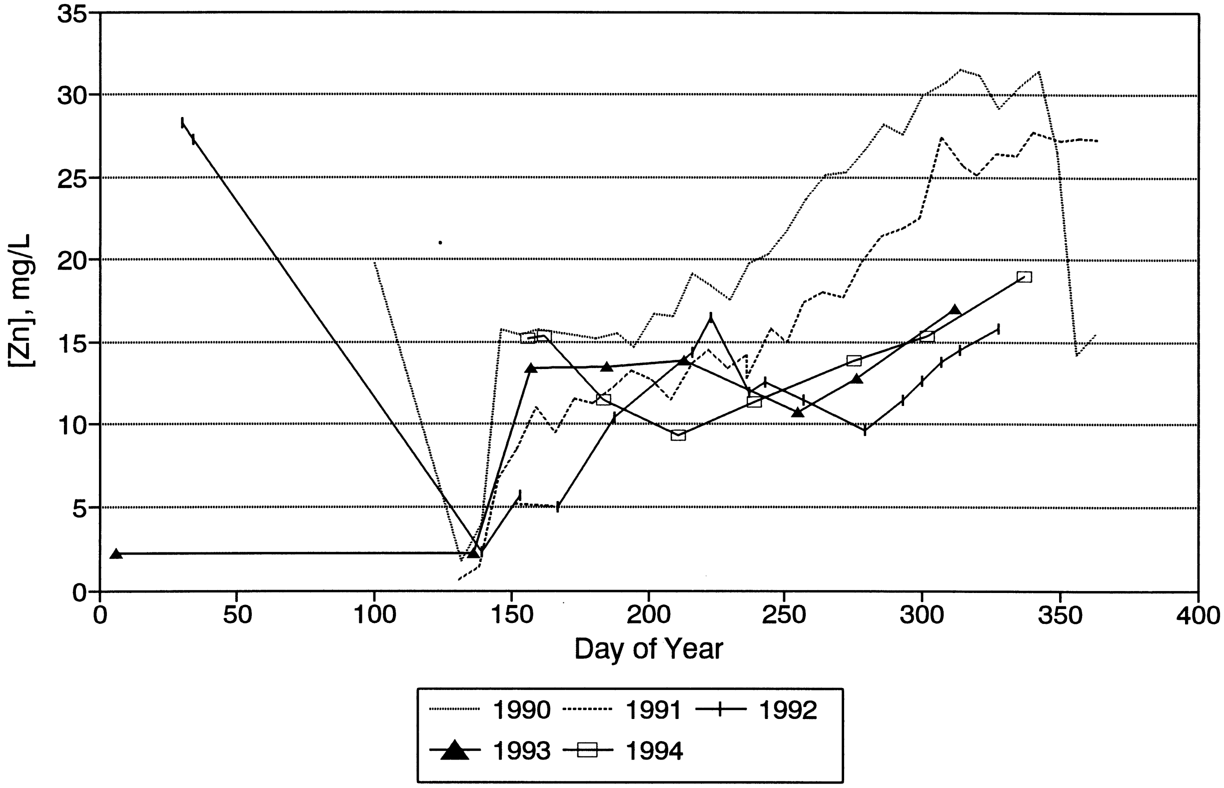


Fig. 12: Lucky Strike Average [Zn]
Annual: Apr. 10, 1990 - Dec. 3, 1994

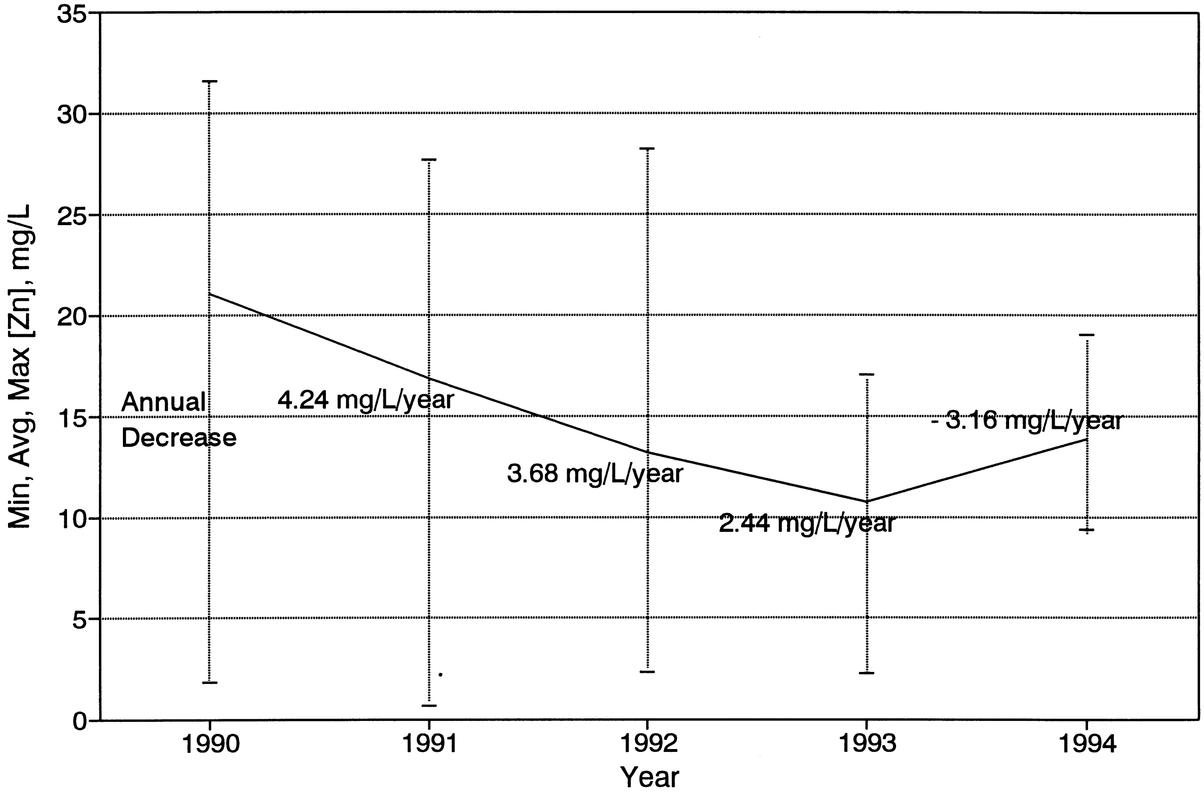


Fig.13: Lucky Strike Zinc Concentration
April, 1989, 1991, 1992, 1993, 1994

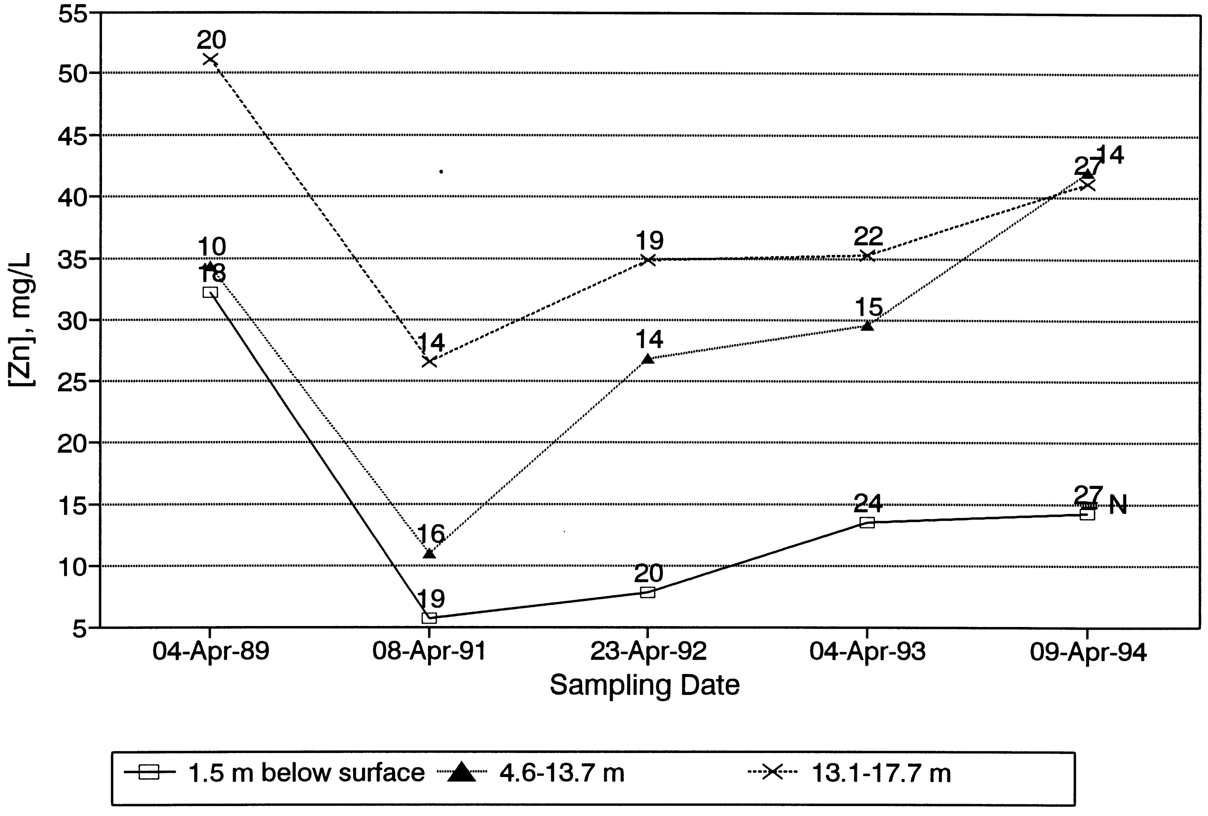


Fig. 14: Lucky Strike Pond Elevation
VS Drainage Tunnel Flow

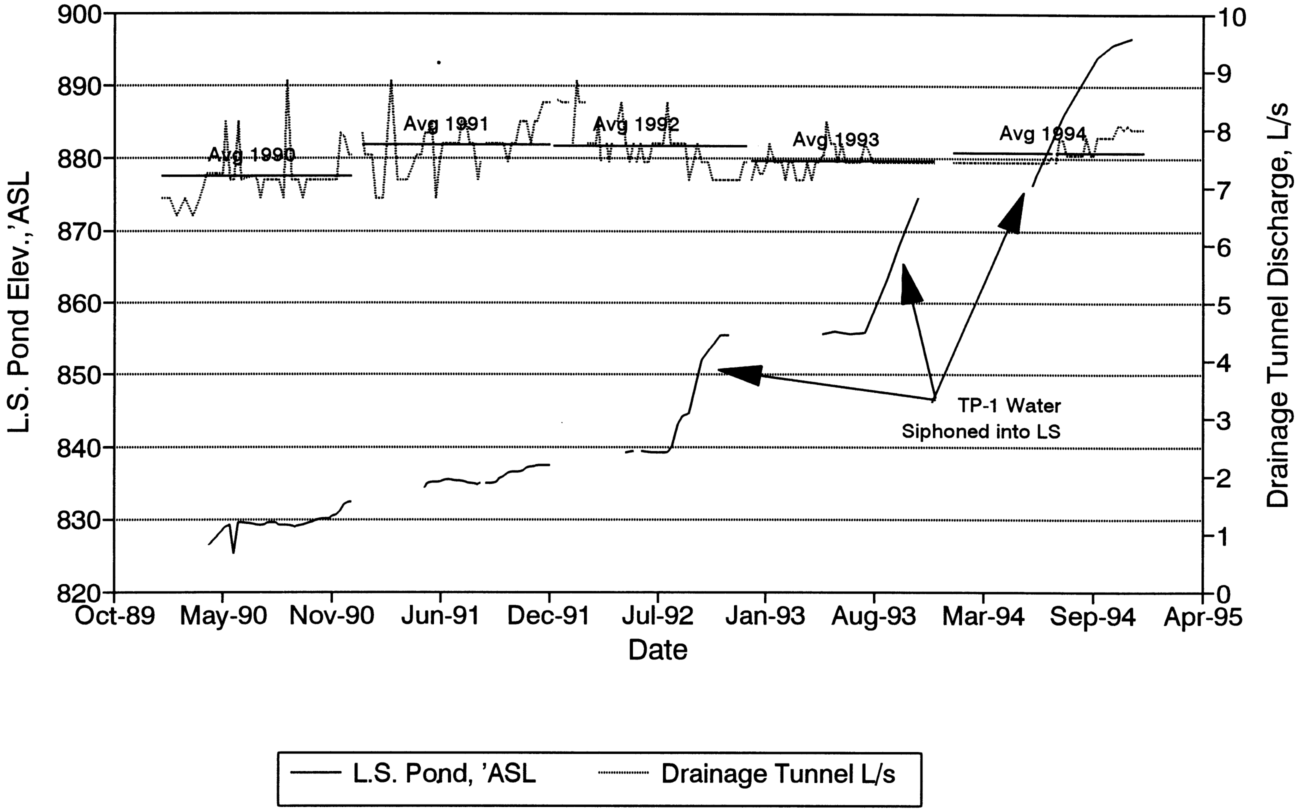


Fig. 15: TP-1 Zinc Concentrations
May 12, 1990 - Dec. 25, 1994

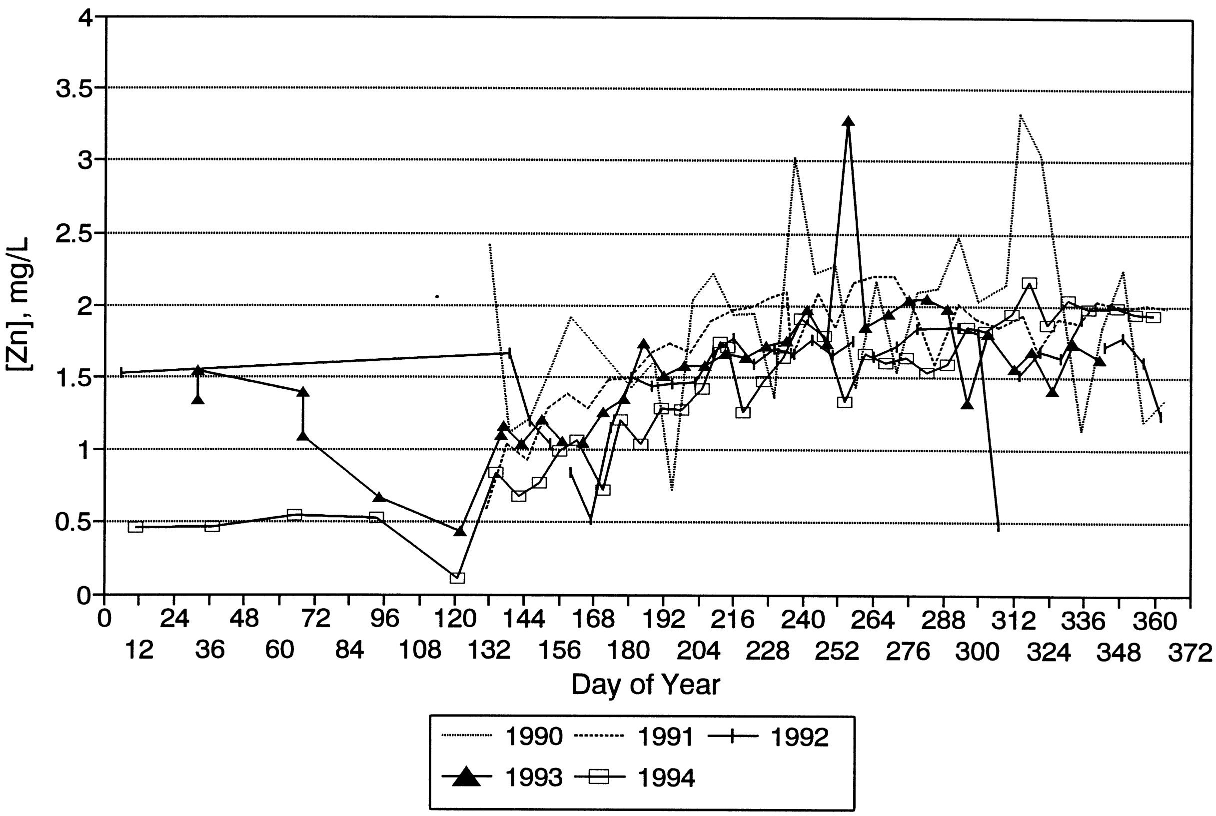


Fig. 16: TP-1 Outflow
May 12, 1990 - Dec. 25, 1994

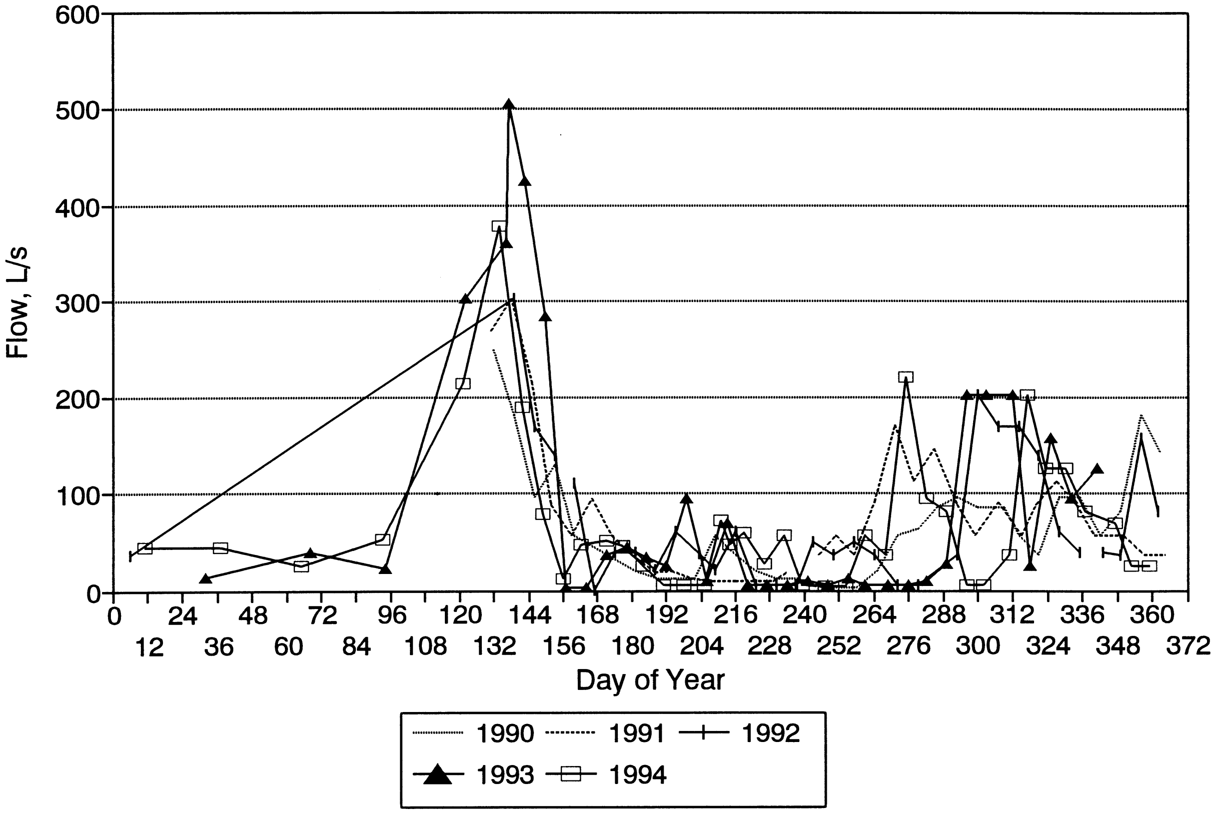


Fig. 17: TP-2 Zinc Concentrations
May 12, 1990 - Dec 25, 1994

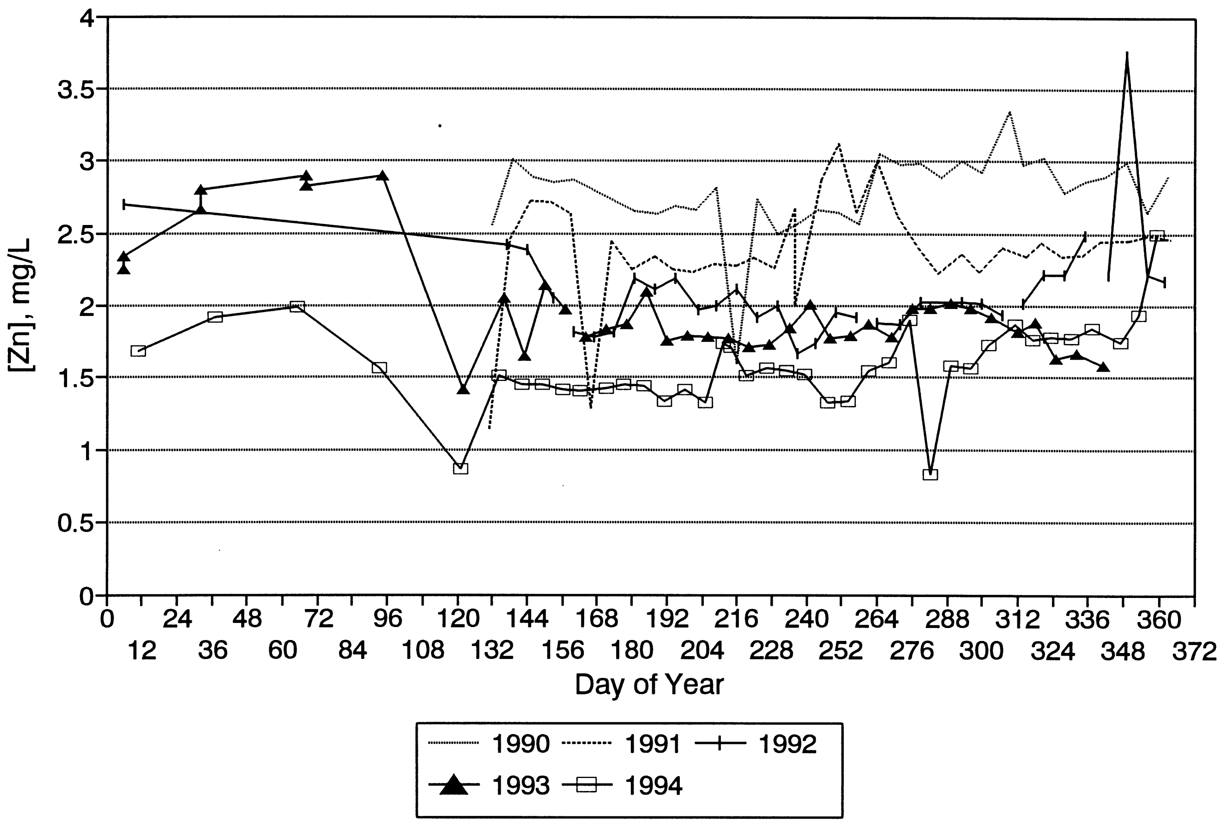


Fig. 18: TP-2 Outflow
May 12, 1990 - Dec. 25, 1994

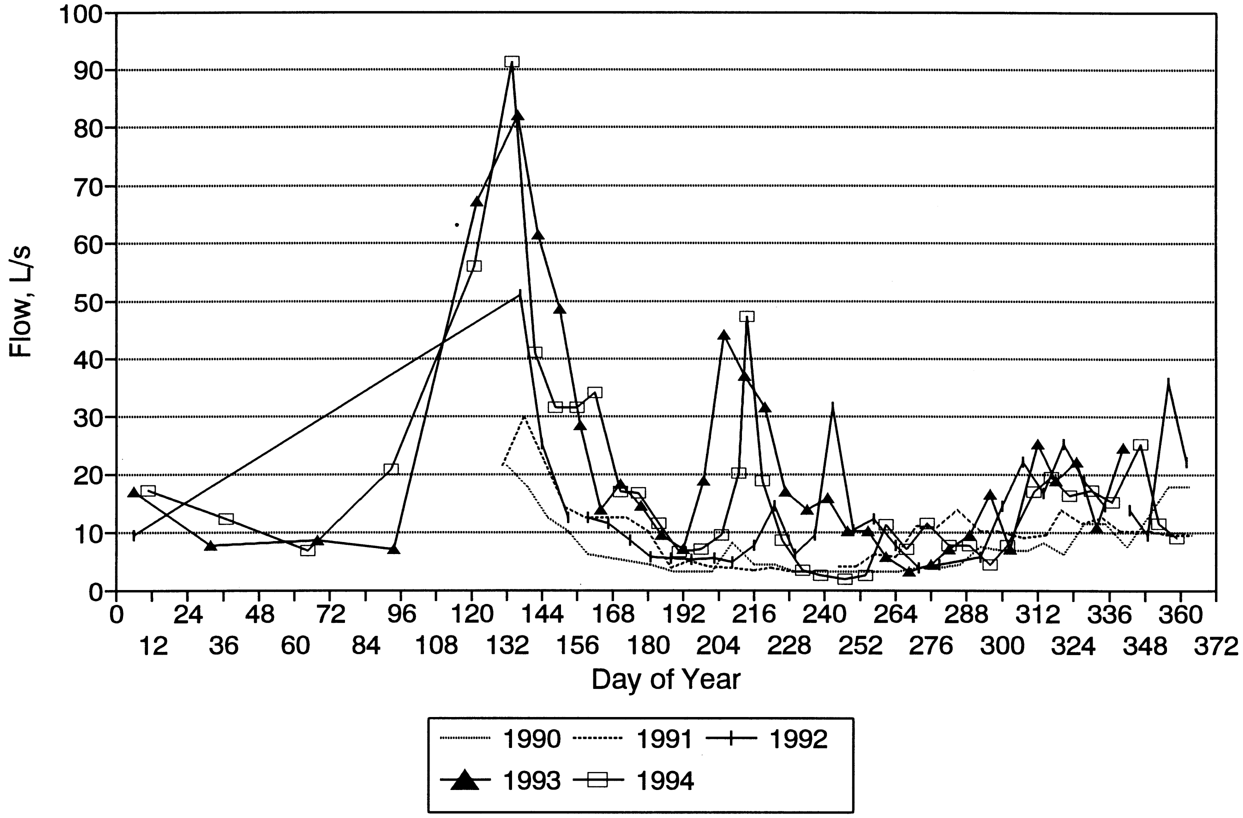


Fig. 19: TP-2 Outflow Average [Zn]
Annual: May 12, 1990 - Dec. 25, 1994

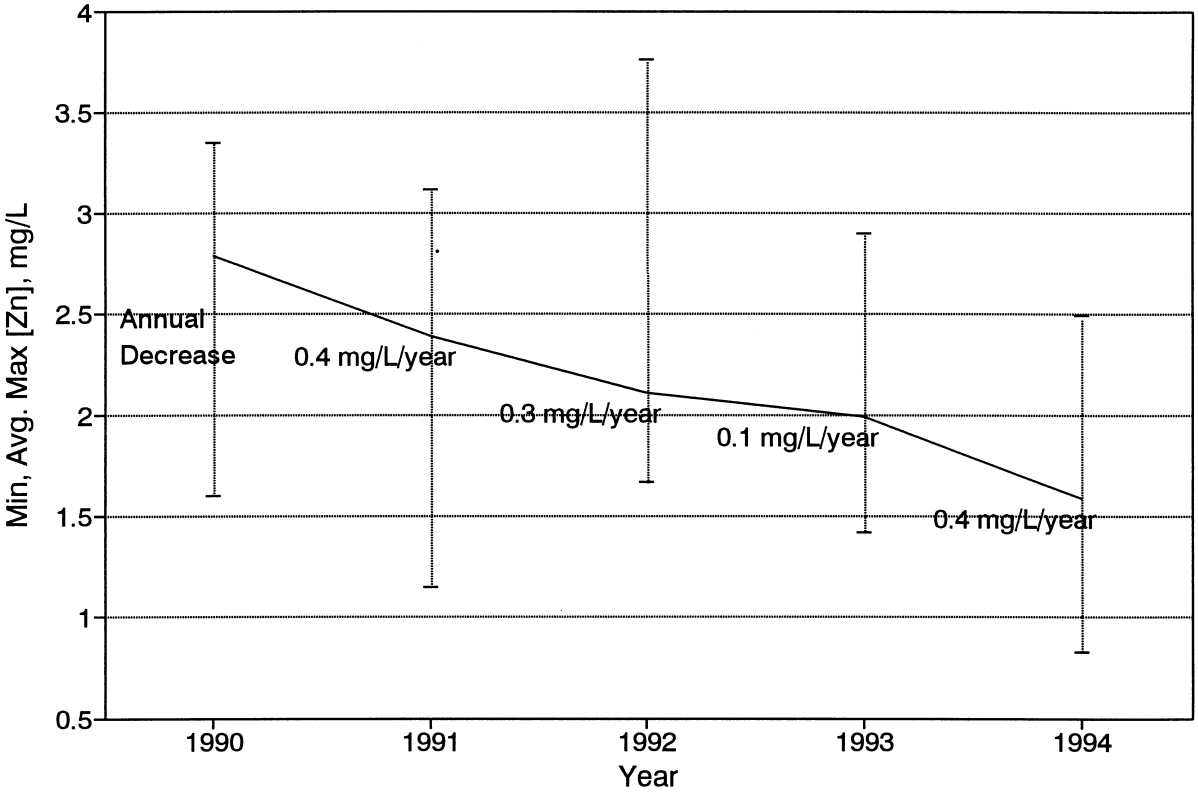


Fig. 20: TP-2 Daily Zinc Loading
May 12, 1990 - Dec. 25, 1994

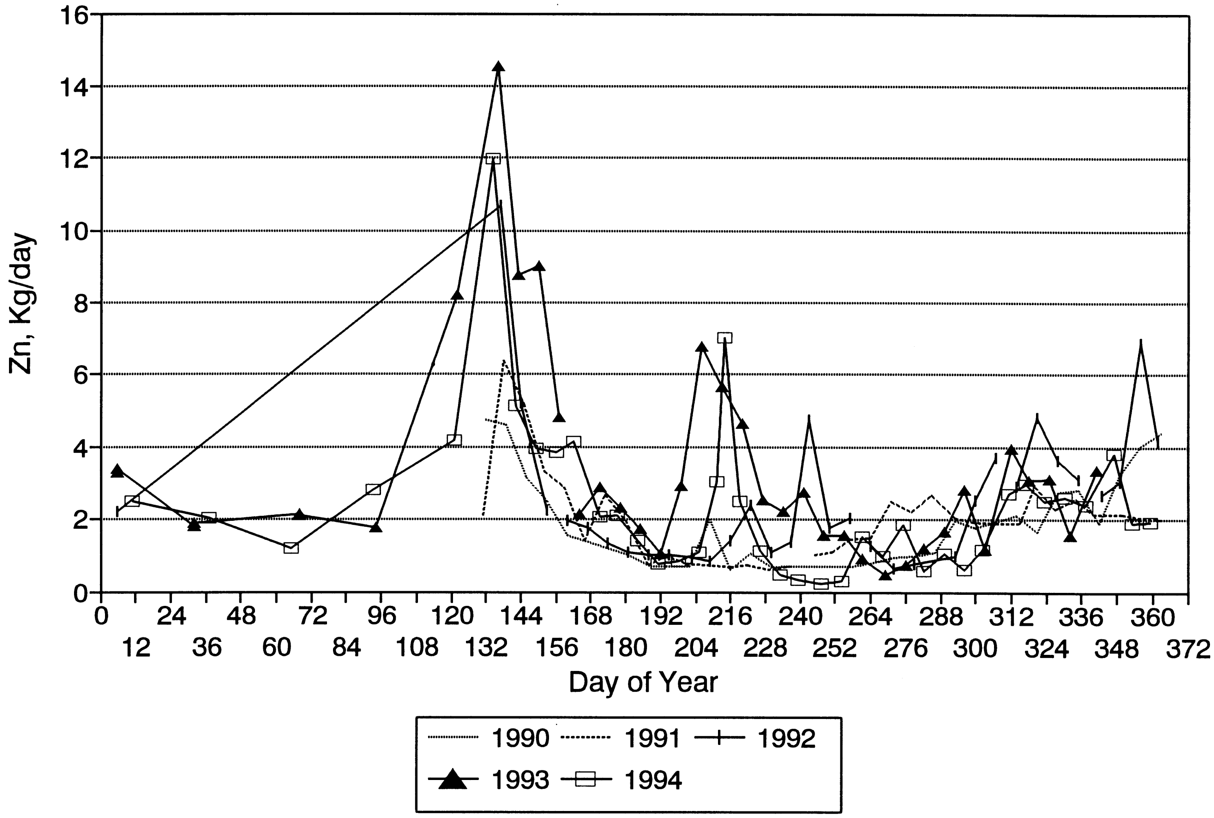


Fig.21: Simms Brook Zinc Concentrations
May 12, 1990 - Dec. 3, 1994

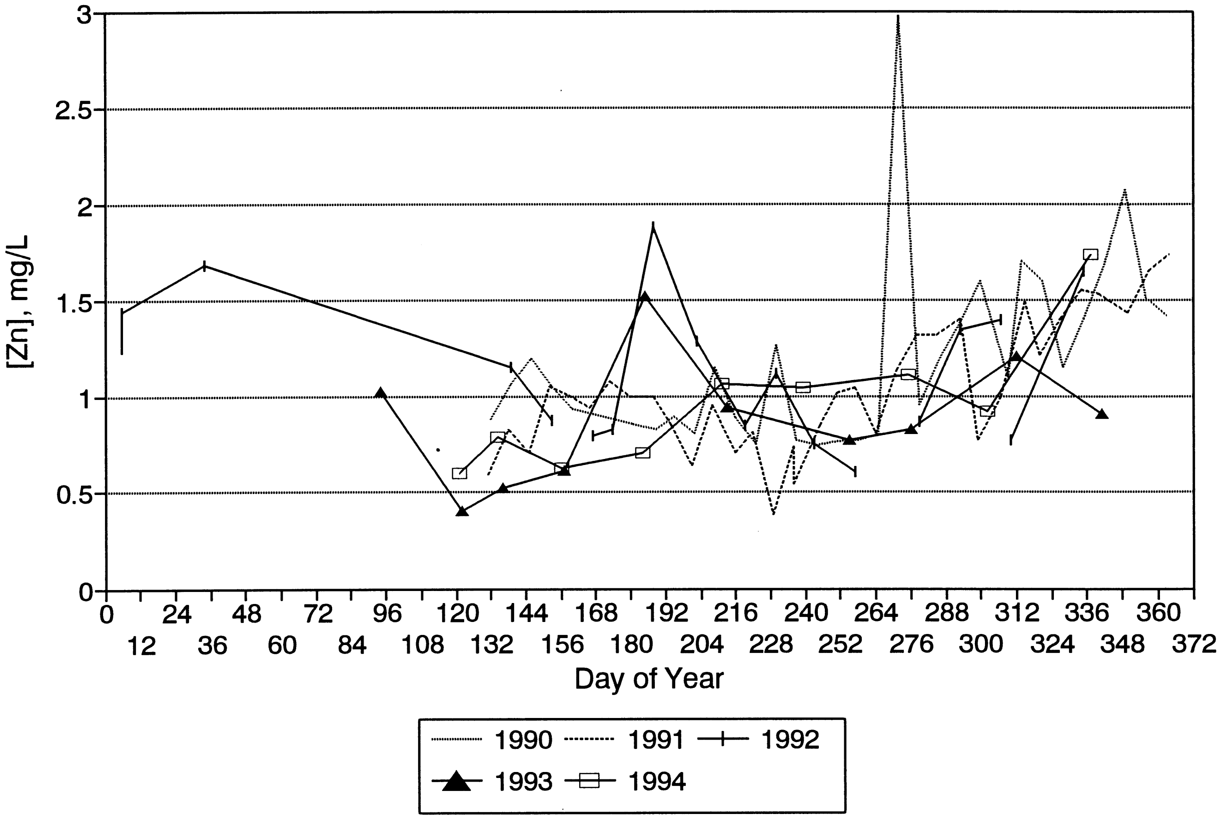


Fig. 22: Simms Brook Flow
May 12, 1990 - Dec. 3, 1994

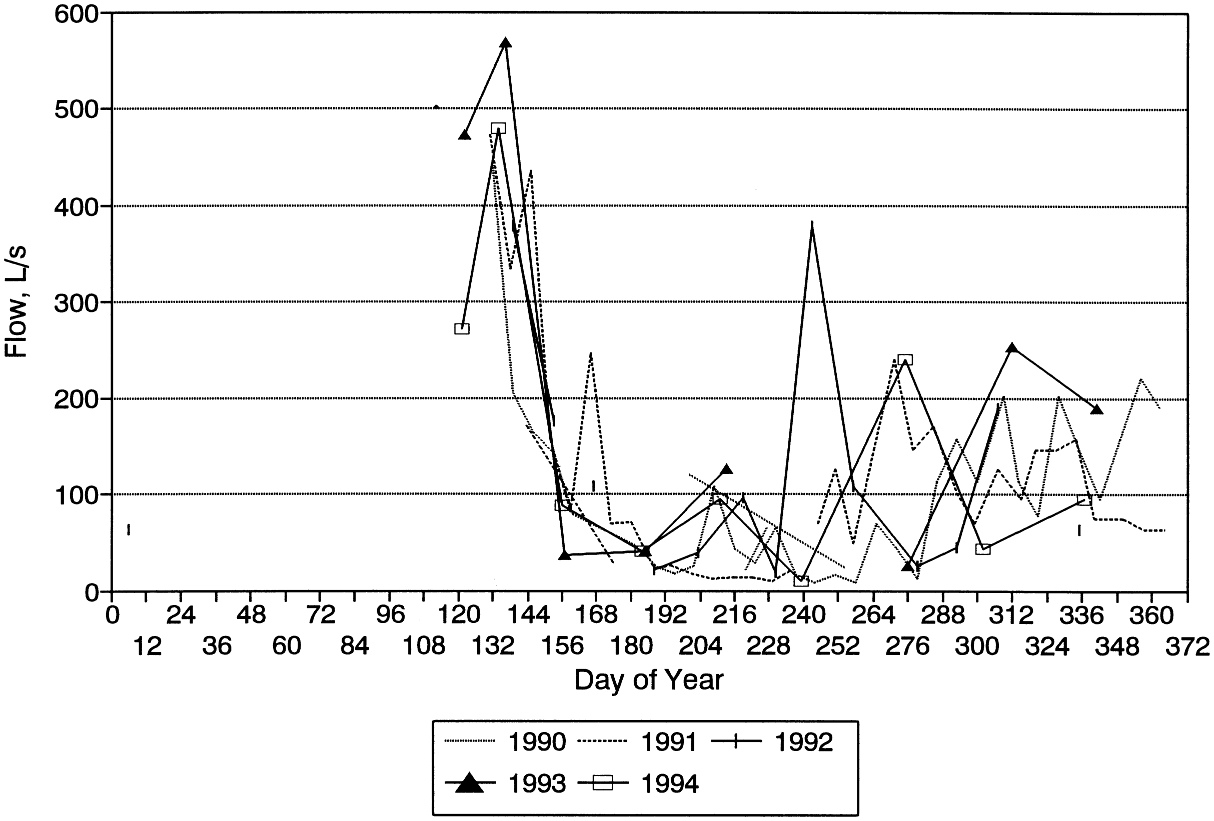


Fig. 23: Buchans R. at Highway
Jan. 13, 1990 - Dec. 3, 1994

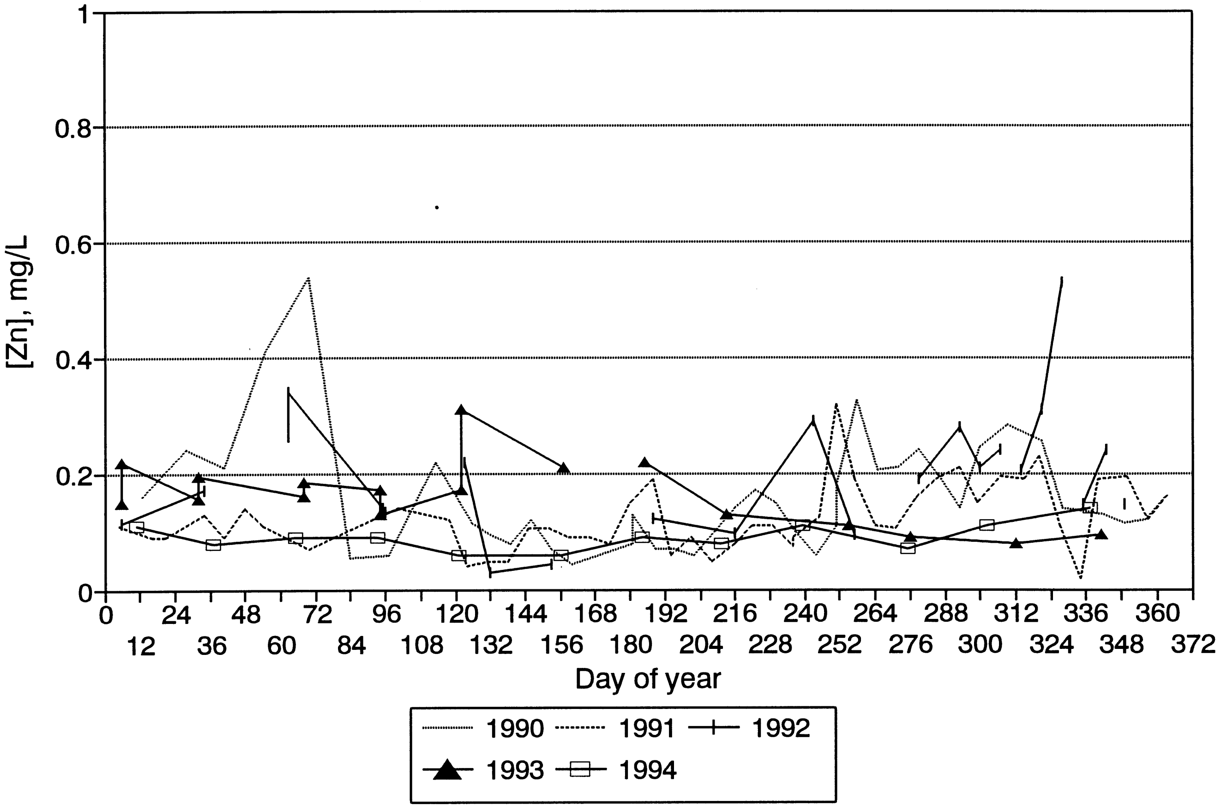


Fig. 24: OWP Centre Limnology
Sep 27, 1993; Jul 11,15, Sep 7, 1994

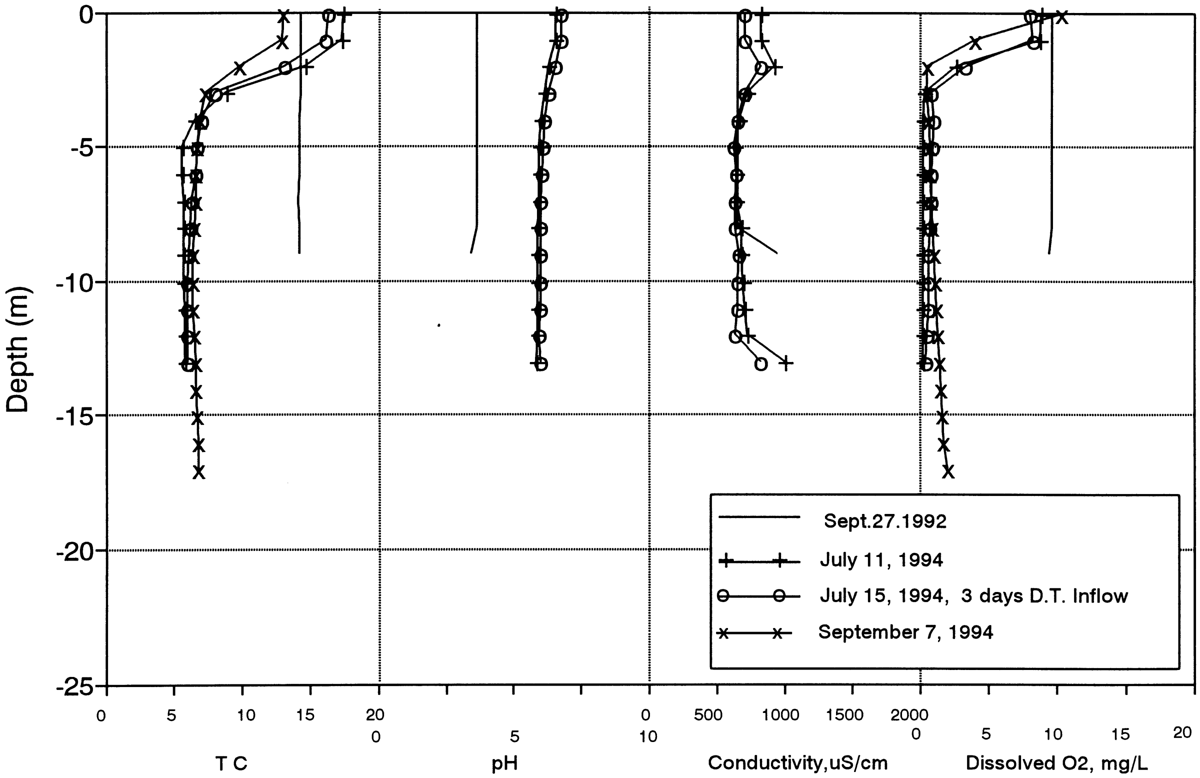


Fig. 25: OEP Centre Limnology
Sept 27, 1992, July 11, Sept7, 1994

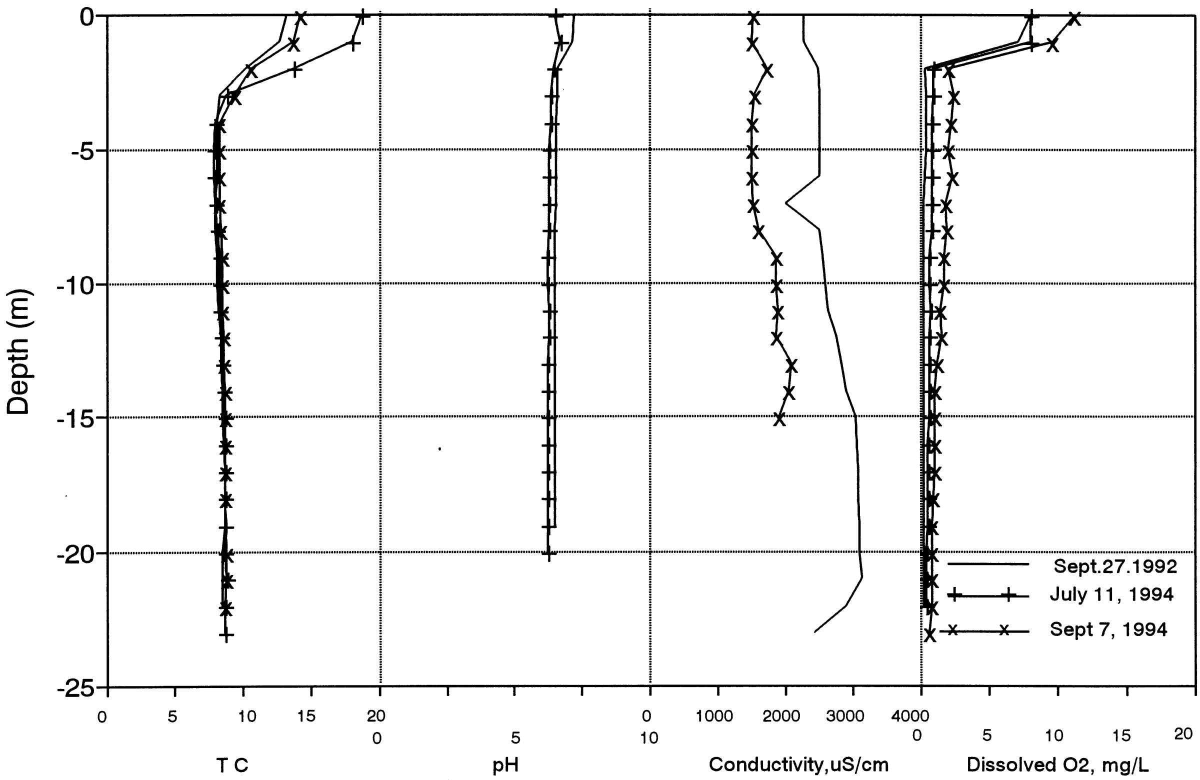


Fig.26a: OWP Limnocorrals
Surface Water pH

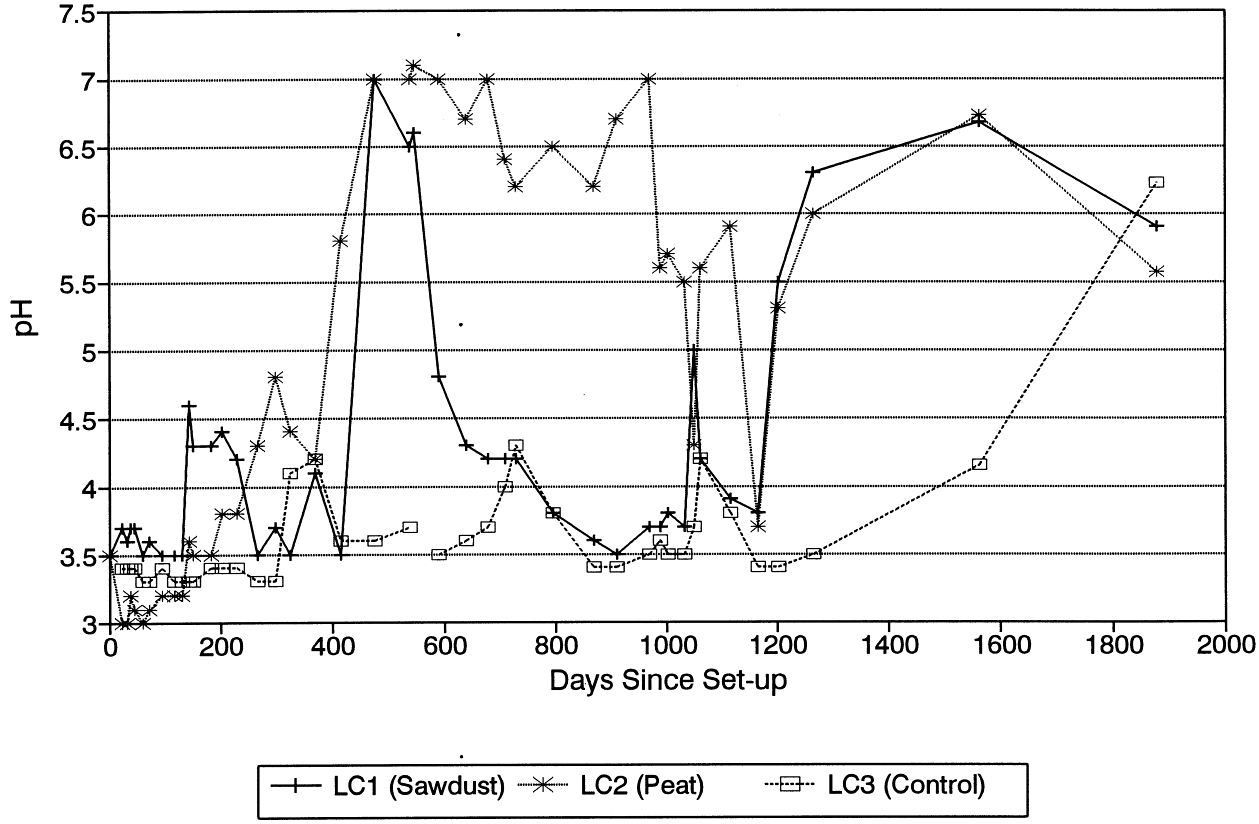


Fig.26b: OWP Limnocorrals
Bottom Water pH

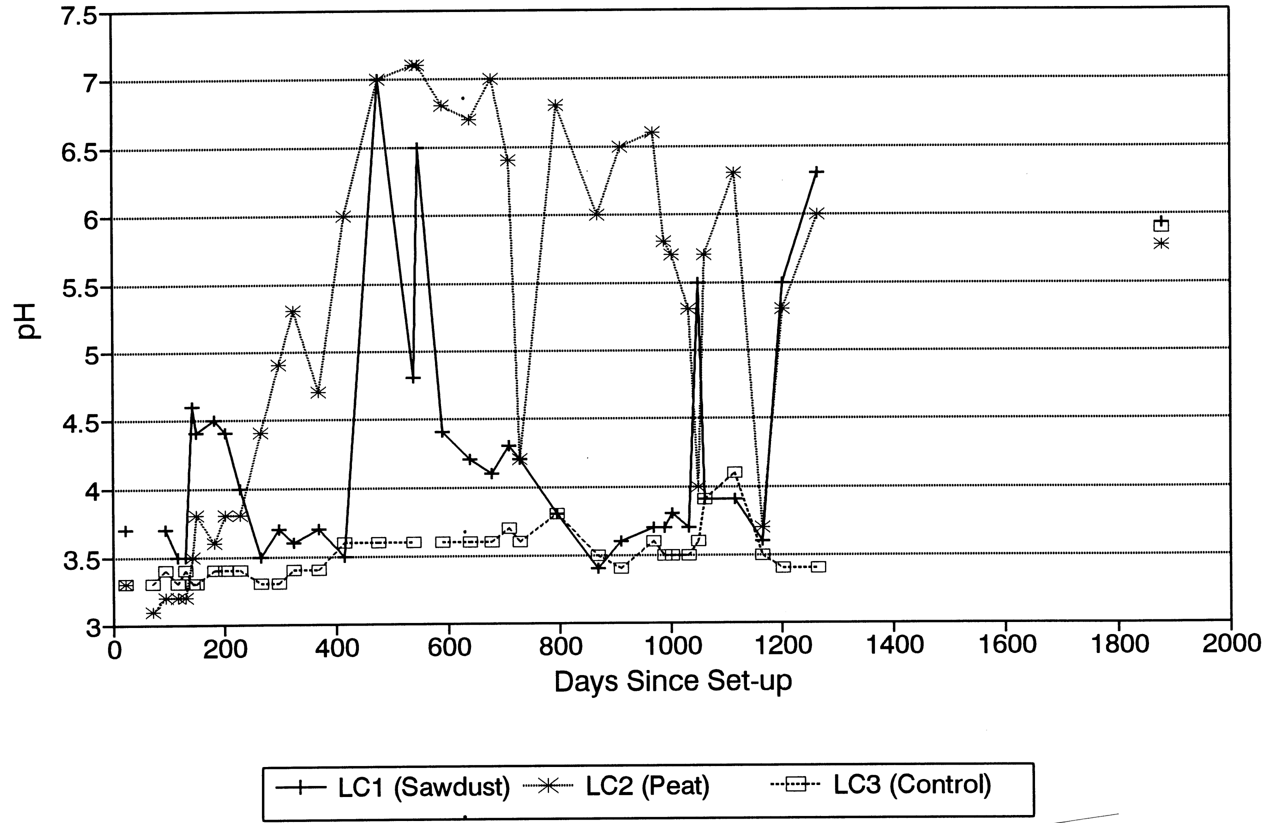


Fig.27a: OWP Limnocorrals
Surface Water [Zn]

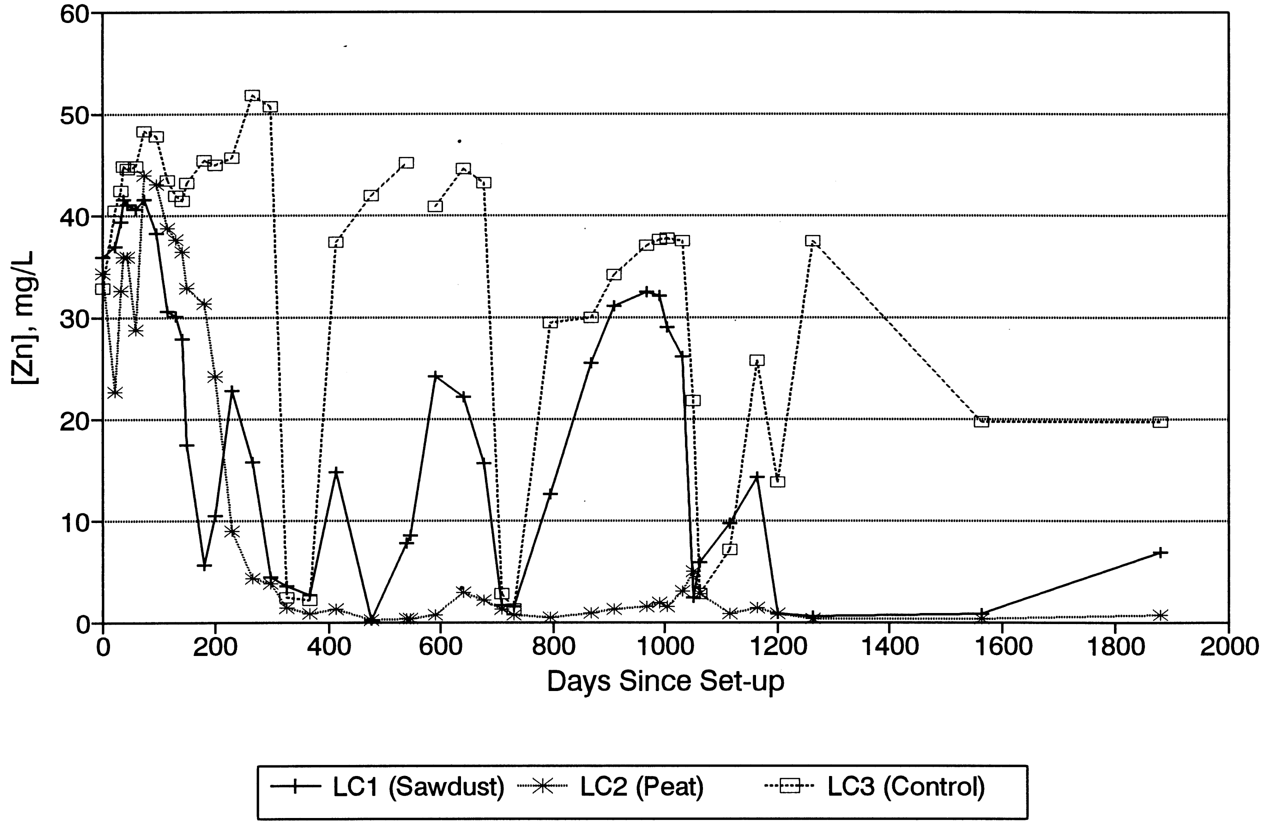


Fig.27b: OWP Limnocorrals
Bottom Water [Zn]

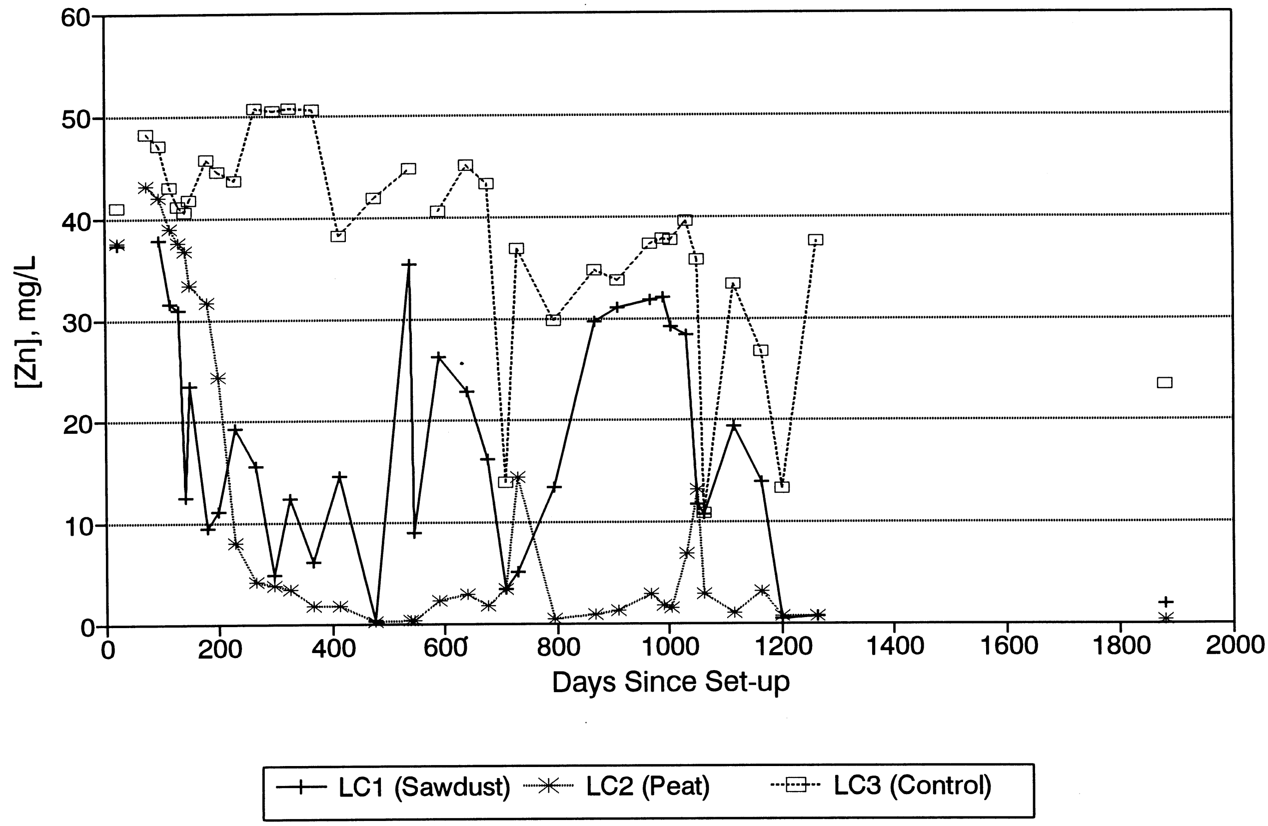


Fig.28a: OEP Limnocorrals
Surface Water pH

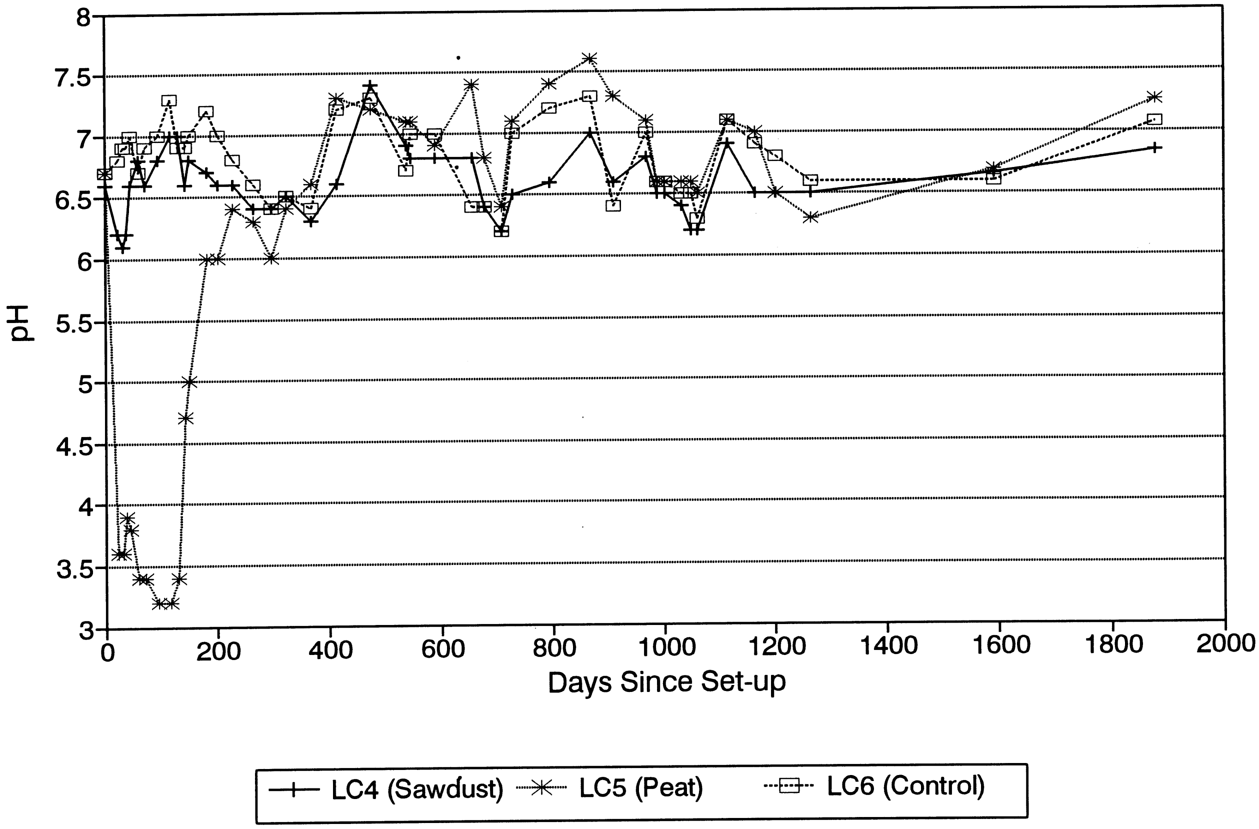


Fig.28b: OEP Limnocorrals
Bottom Water pH

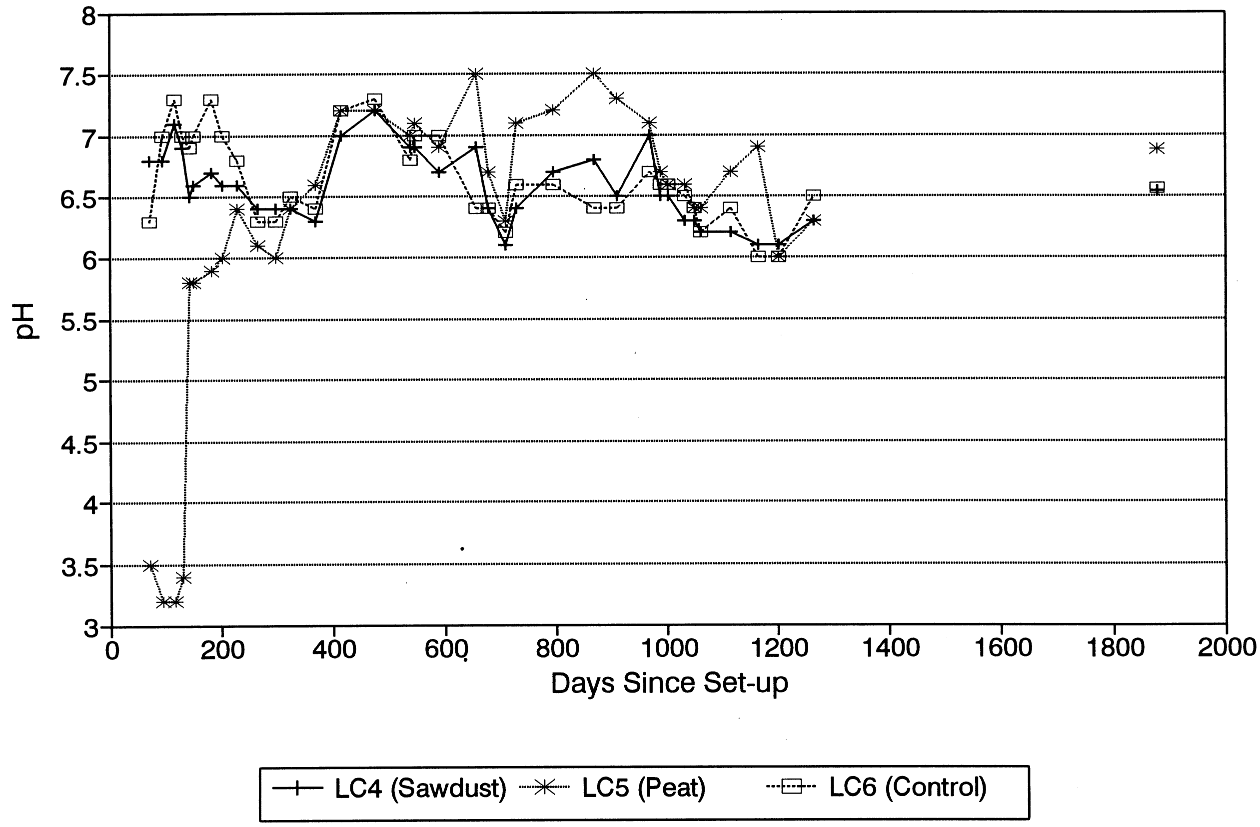


Fig.29a: OEP Limnocorrals
Surface Water [Zn]

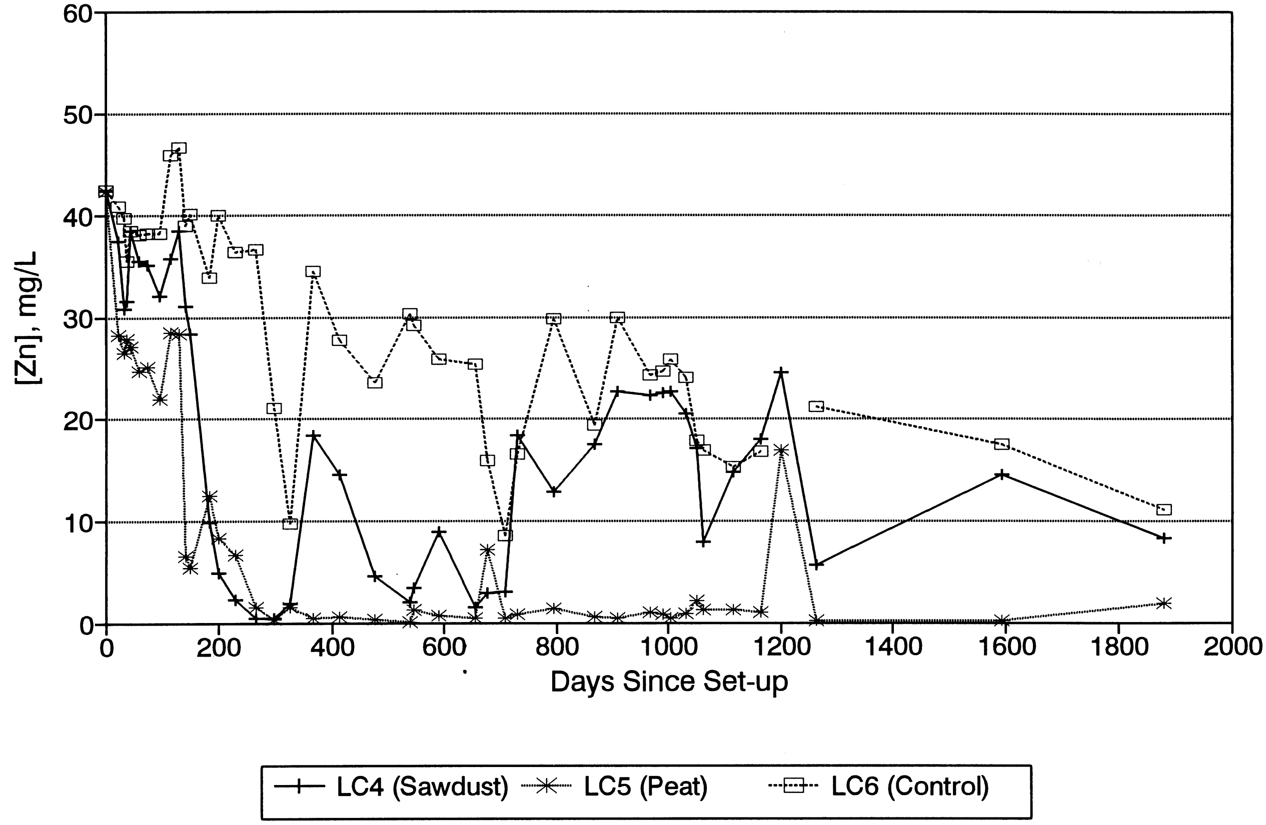


Fig.29b: OEP Limnocorrals
Bottom Water [Zn]

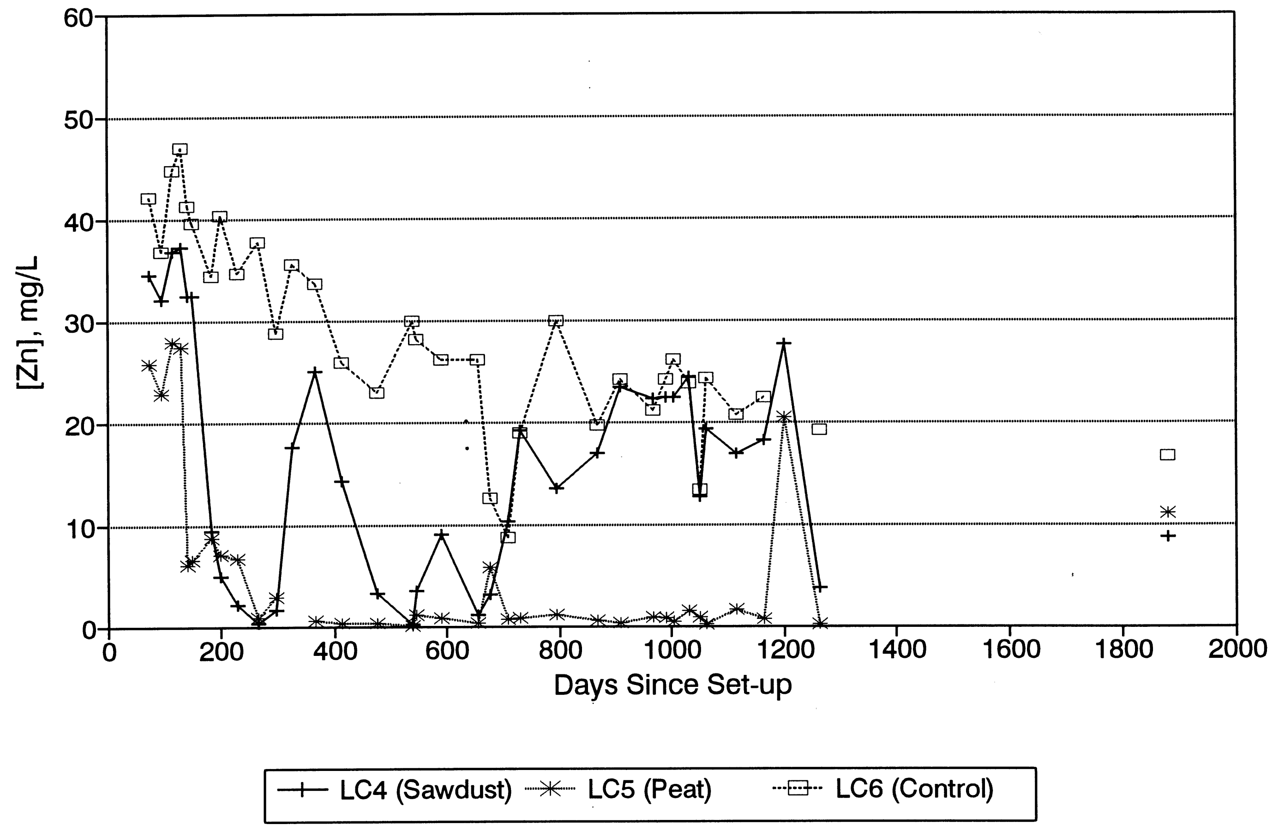


Fig. 30: Sedimentation Rates in OEP
Periods Between Sep 20,90-July 11,1994

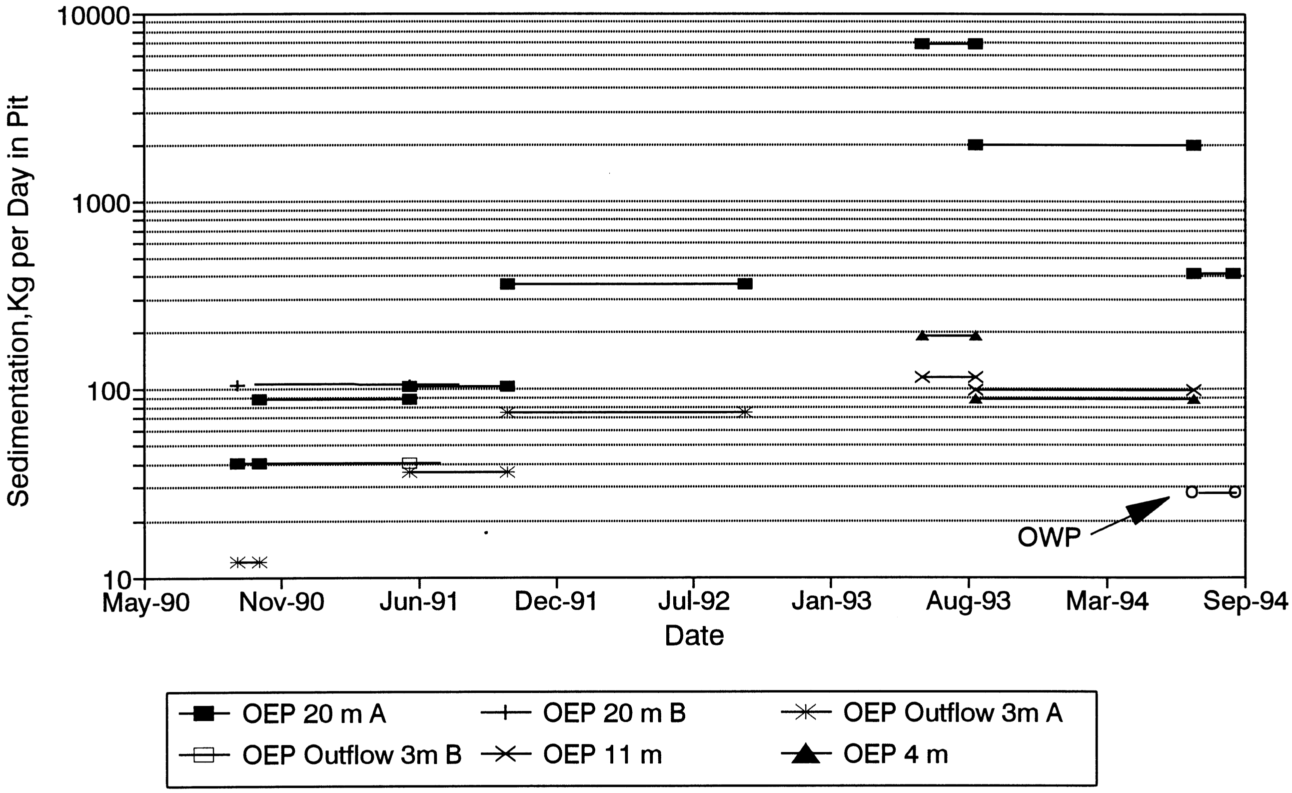


Fig. 31a: Acidity titration curves
Polishing Ponds 1-6, July 12, 1994

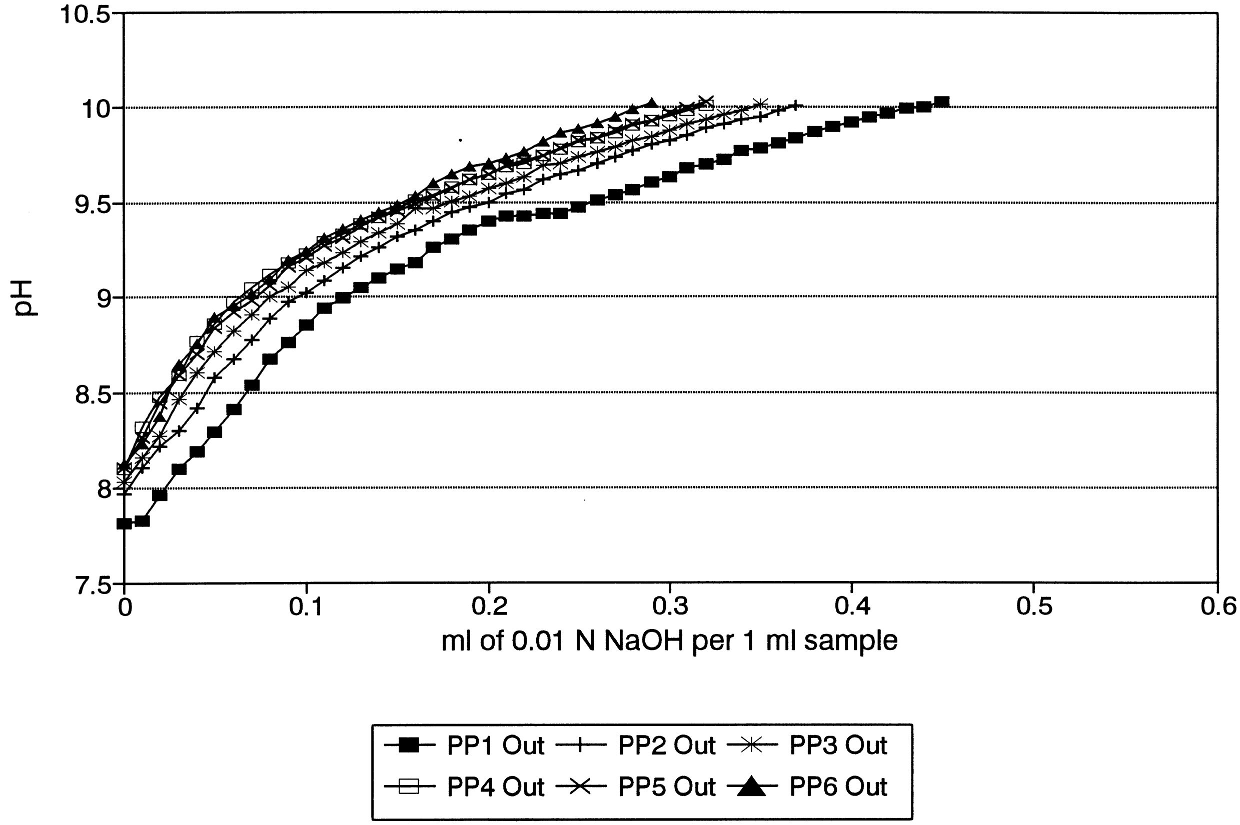


Fig. 31b: Alkalinity titration curves
Polishing Ponds 1-6, July 12, 1994

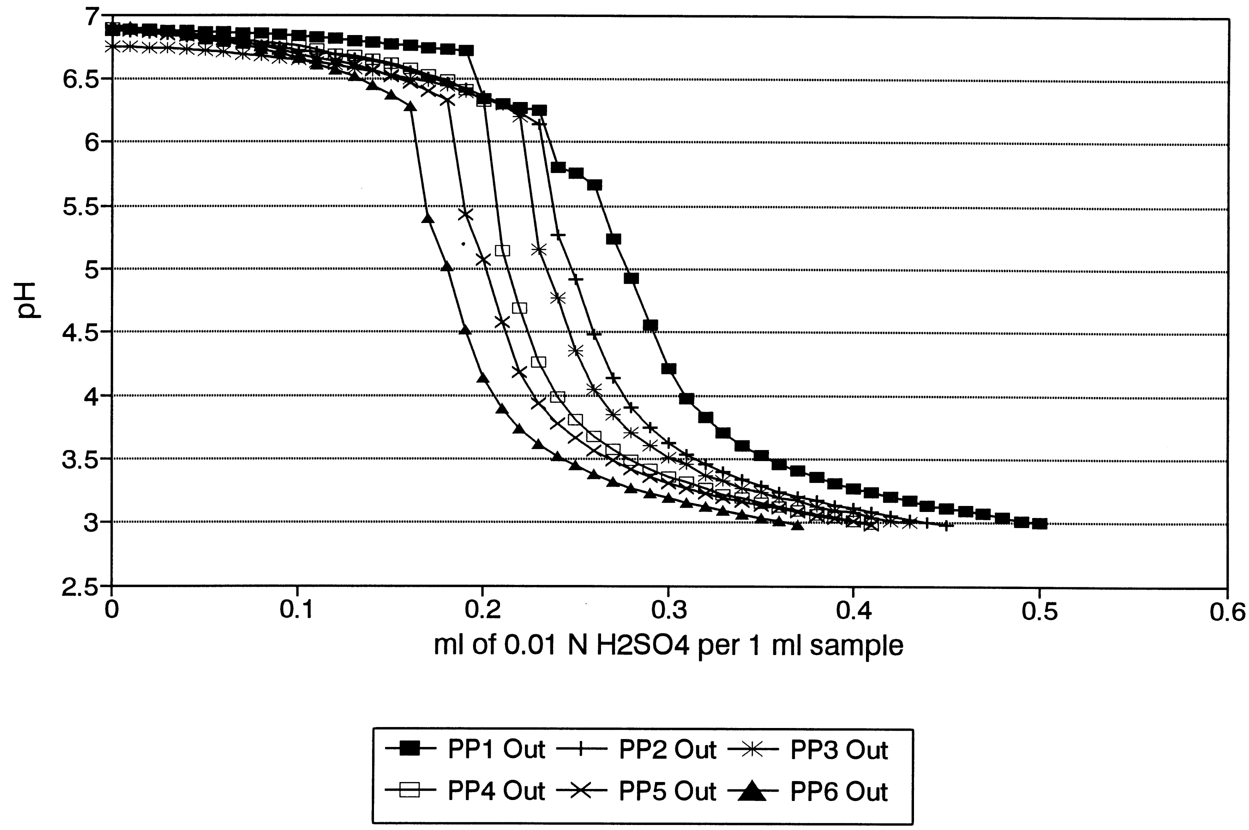


Fig. 32a:Polishing Ponds 10 -13
July 13, 1994 Acidity Titration Curves

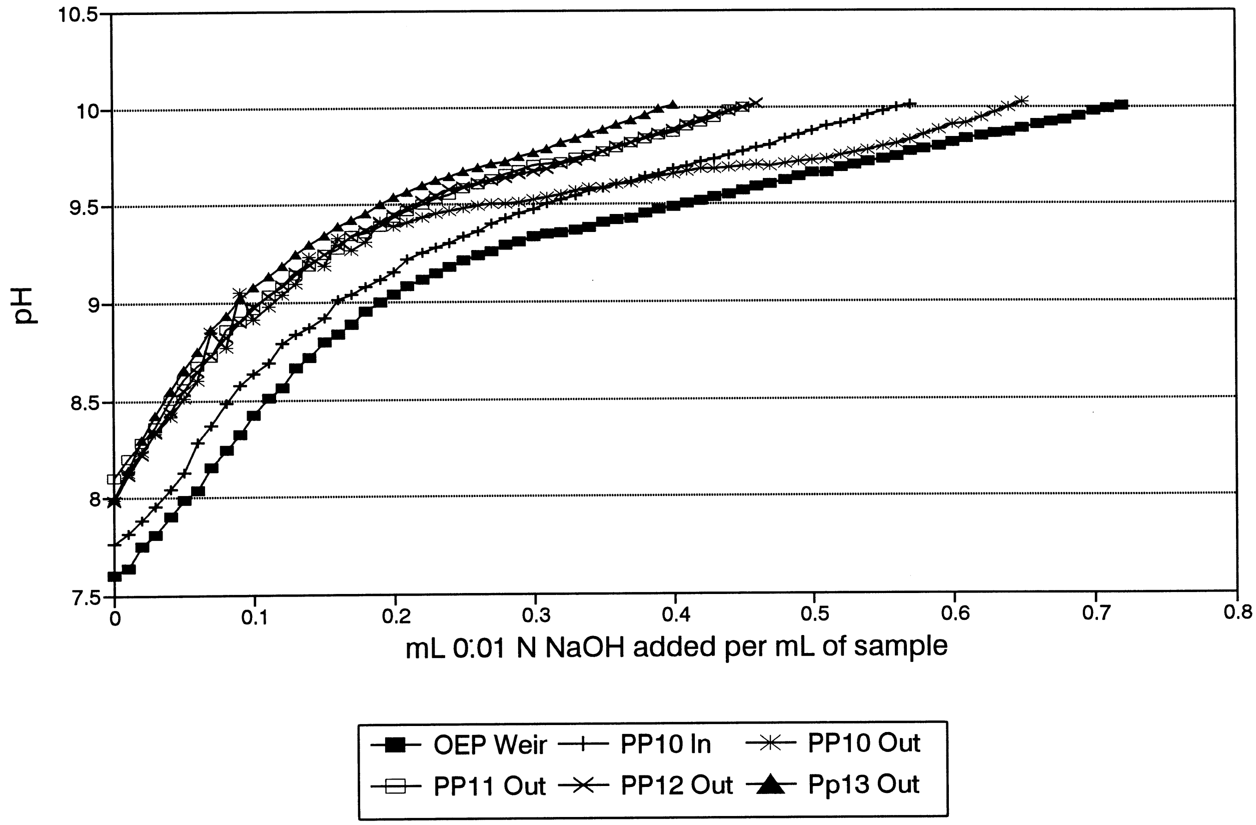


Fig. 32b:Polishing Ponds 10 -13
July 13, 1994 Alkal Titration Curves

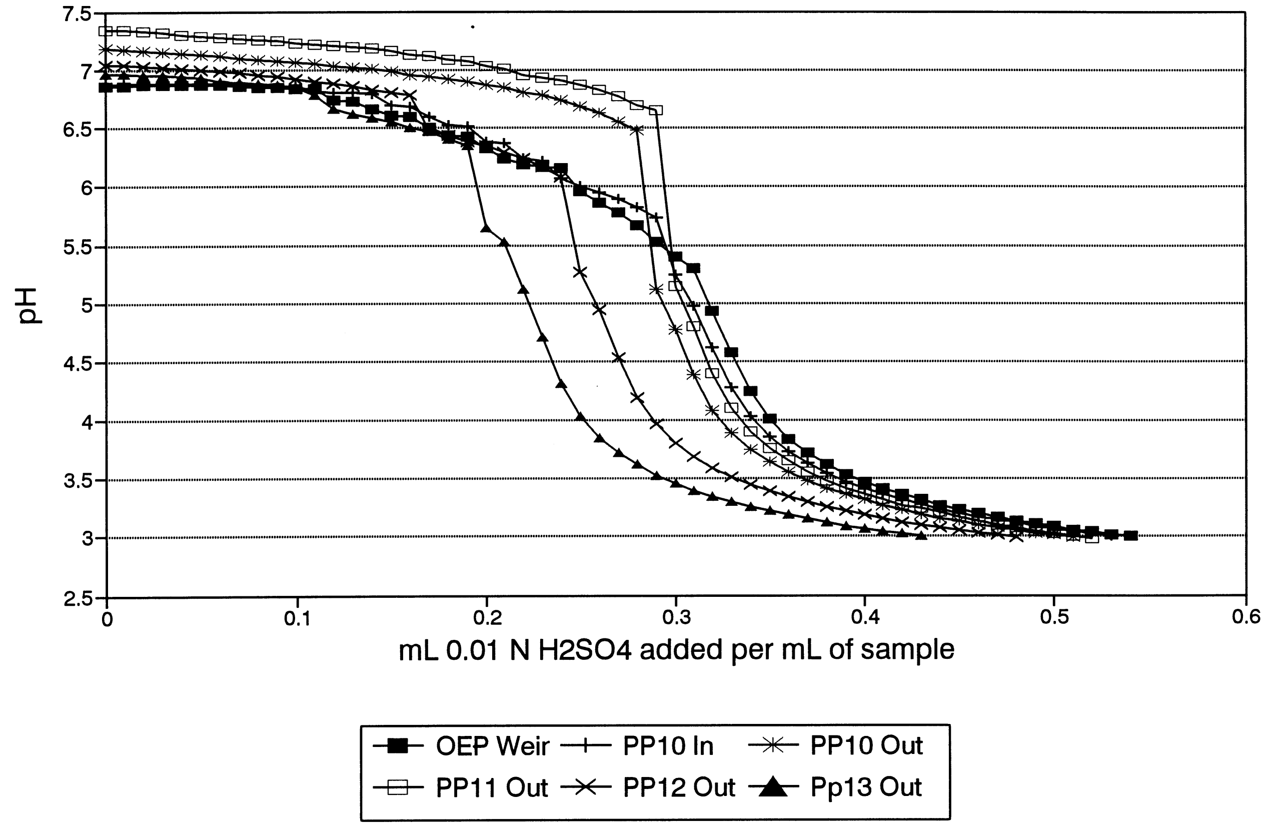


Fig. 33: %[Zn] Decrease vs R.T (days)
PP 10-13: 1992 and 1993 Data

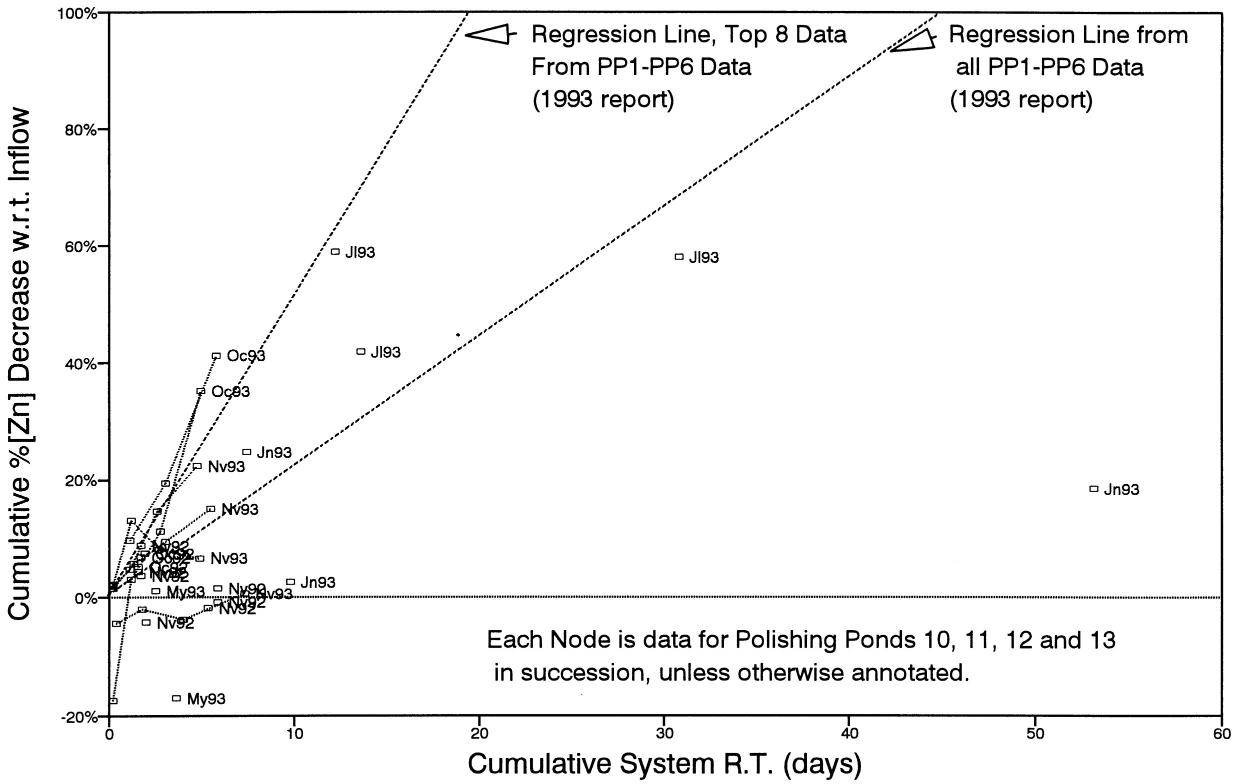


Fig. 34: %[Zn] Decrease vs R.T (days)
PP 10-13: 1994 Data

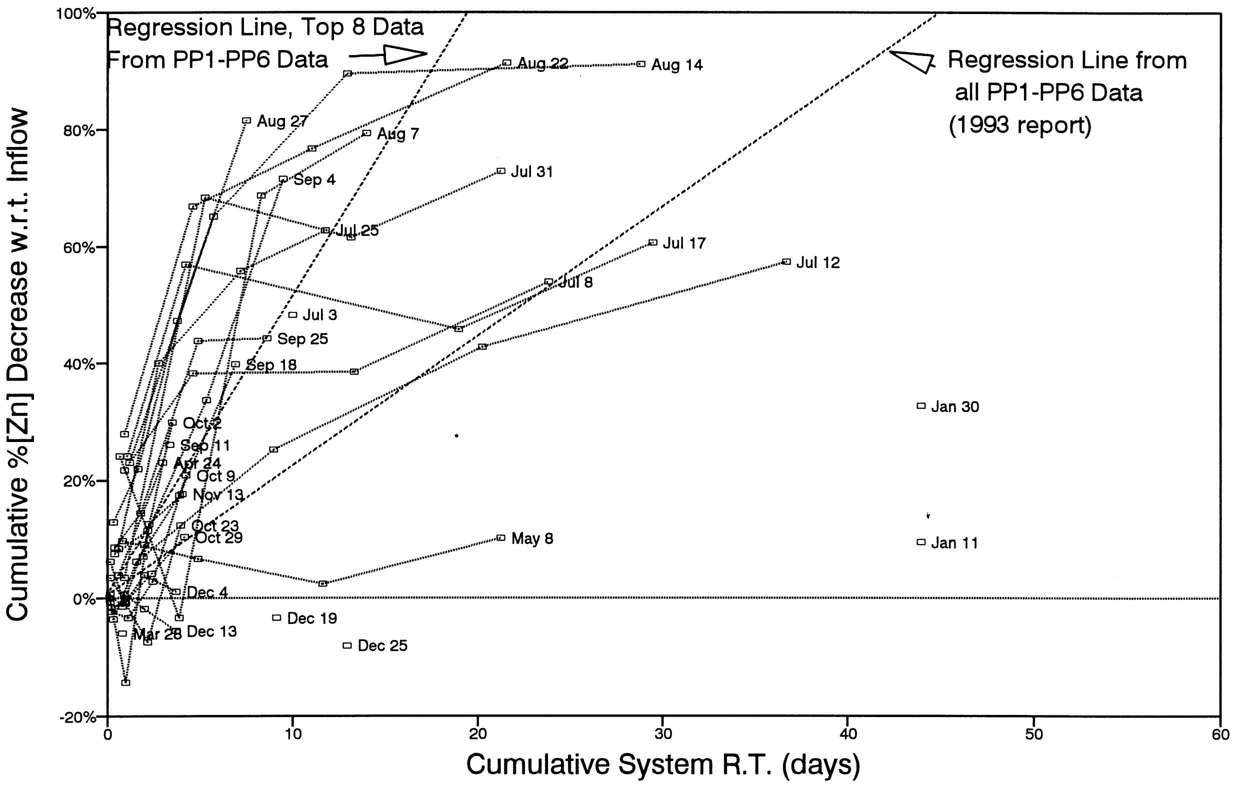
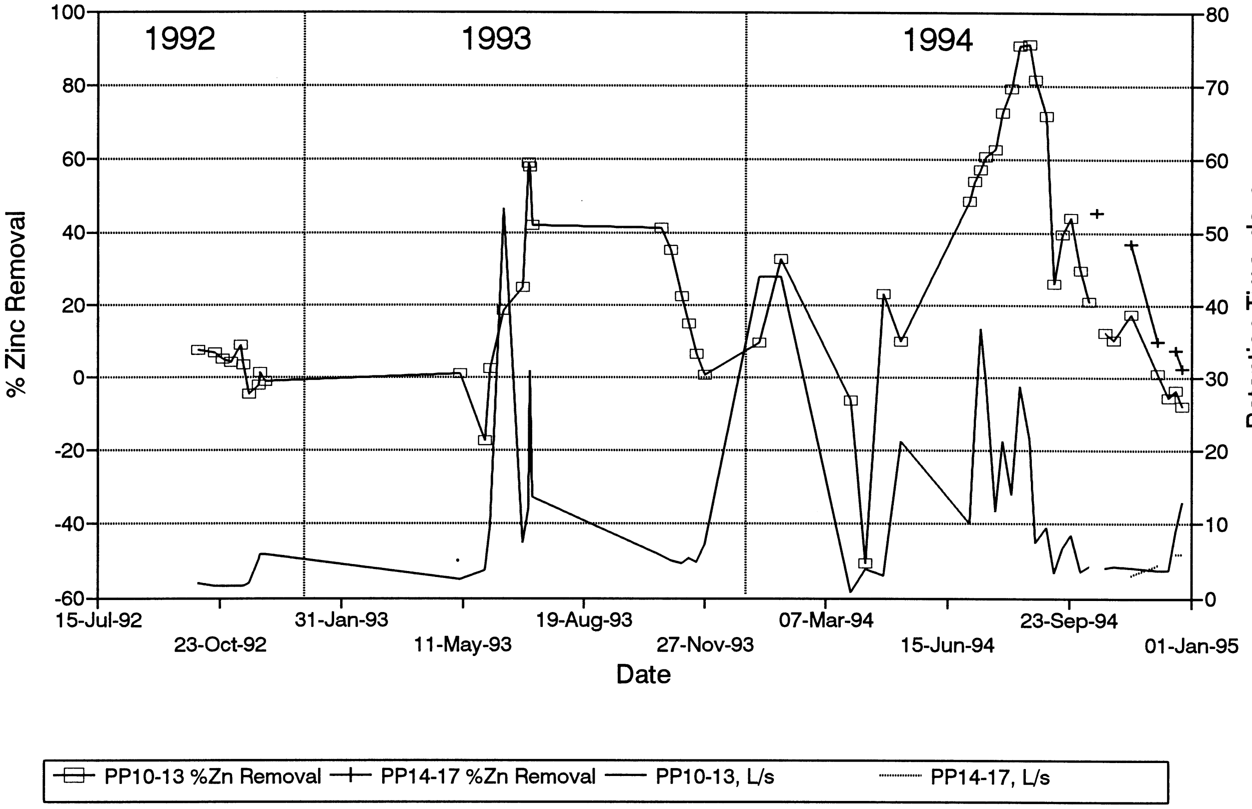
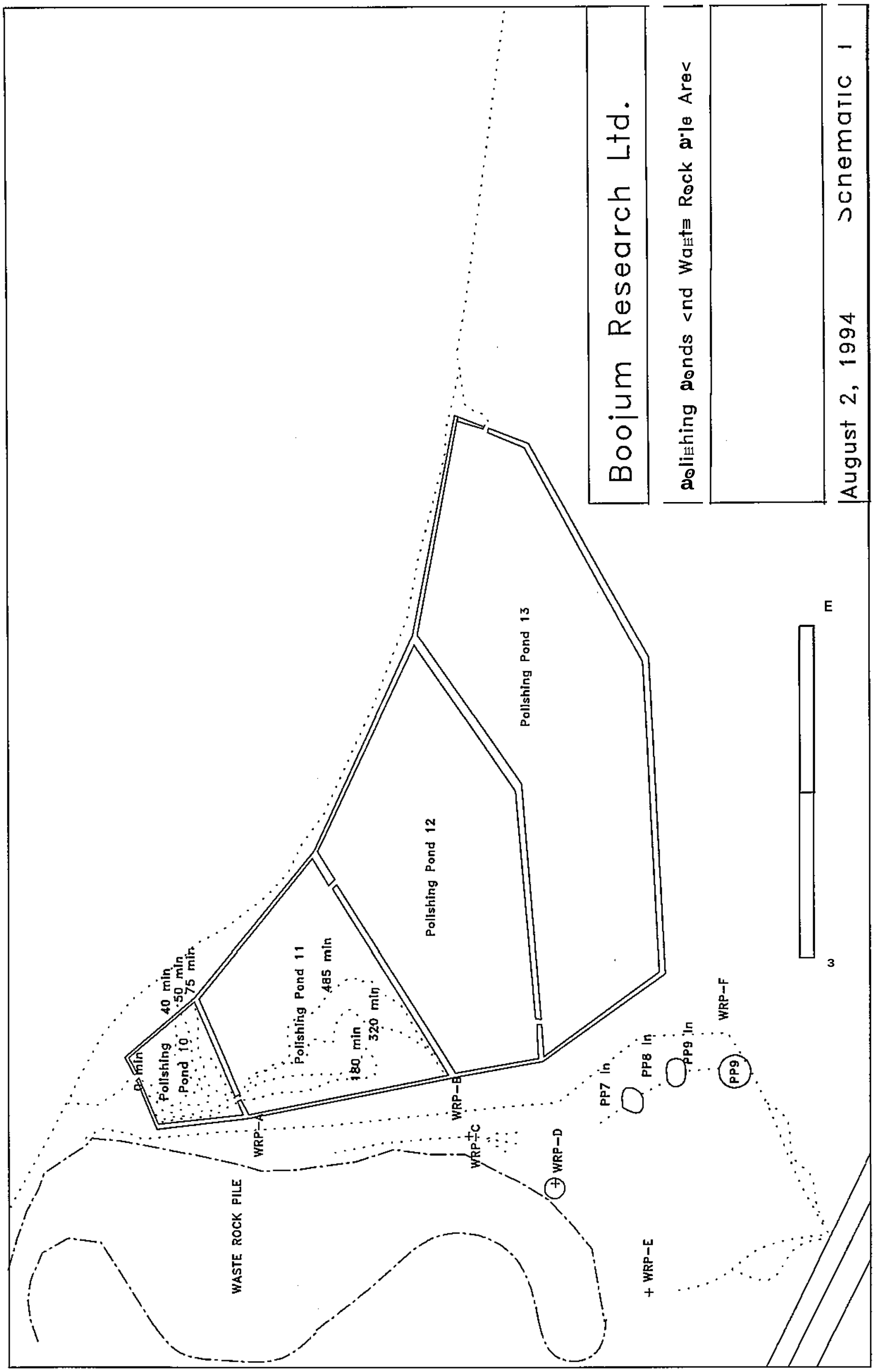
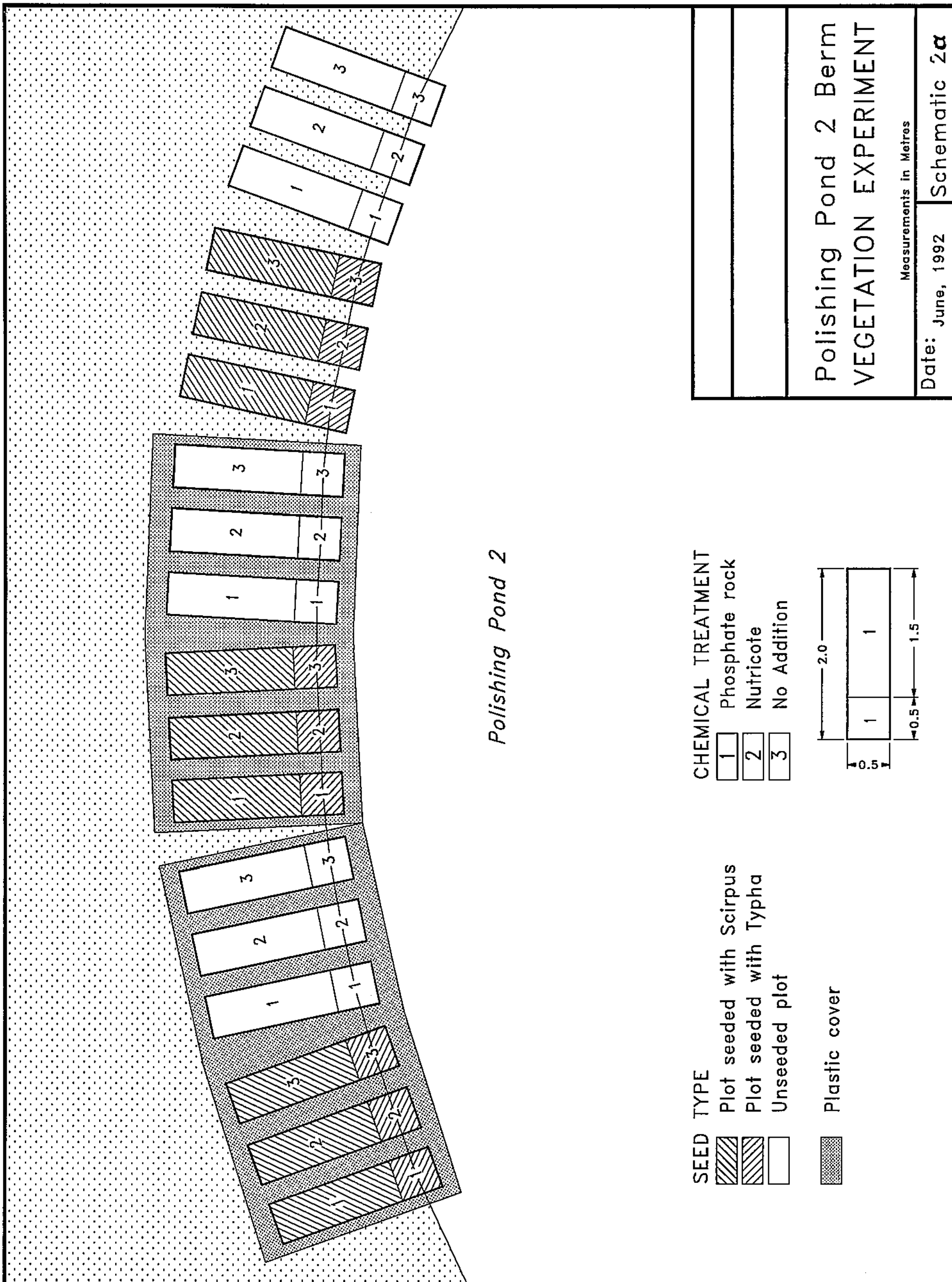
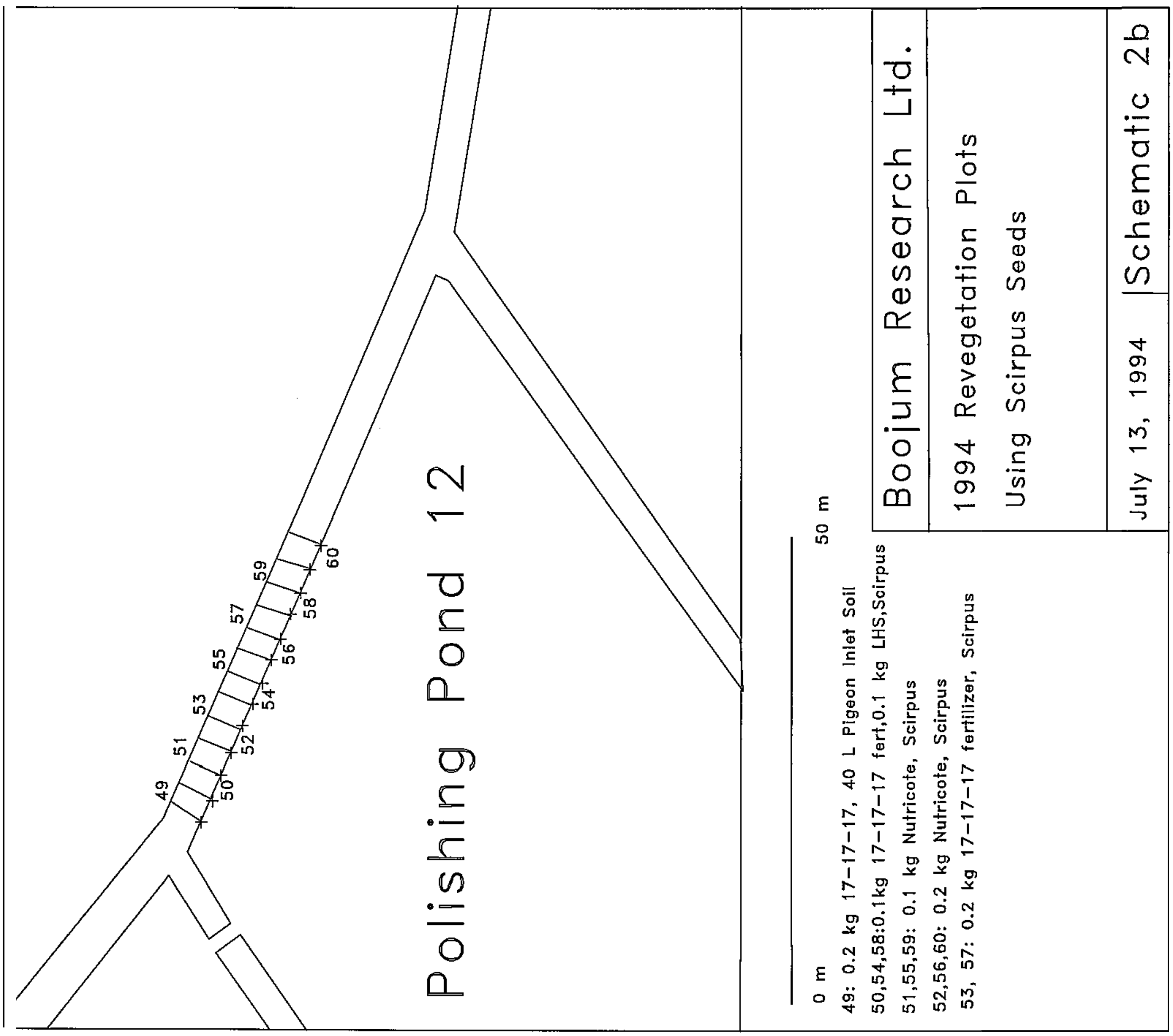


Fig. 35: Polishing Pond Performance
PP 10-13 and PP 14-17




Boojum Research Ltd.
Polishing Ponds and Waste Rock Pile Area
August 2, 1994
Schematic 1
Polishing Pond 13
Polishing Pond 12
Polishing Pond 11
Polishing Pond 10
485 min
320 min
180 min
40 min
50 min
75 min
WASTE ROCK PILE
WRP-A
WRP-B
WRP-C
WRP-D
WRP-E
WRP-F
PP7 In
PP8 In
PP9 In
PP9
E


Polishing Pond 2 Berm
VEGETATION EXPERIMENT
Measurements in Metres
Date: June, 1992
Schematic 2a
Polishing Pond 2
CHEMICAL TREATMENT
1 Phosphate rock
2 Nutricote
3 No Addition
SEED TYPE
Plot seeded with Scirpus
Plot seeded with Typha
Unseeded plot
Plastic cover
2.0
1.5
0.5
0.5


Polishing Pond 12
49
50
51
52
53
54
55
56
57
58
59
60
0 m
50 m
49: 0.2 kg 17-17-17, 40 L Pigeon Inlet Soil
50,54,58:0.1kg 17-17-17 fert,0.1 kg LHS,Scirpus
51,55,59: 0.1 kg Nutricote, Scirpus
52,56,60: 0.2 kg Nutricote, Scirpus
53, 57: 0.2 kg 17-17-17 fertilizer, Scirpus
Boojum Research Ltd.
1994 Revegetation Plots
Using Scirpus Seeds
July 13, 1994
Schematic 2b